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Environmental Security

Integrated Urban Water Resources Management

Edited by
Petr Hlavinek
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Integrated Urban Water Resources Management

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Series C: Environmental Security

Integrated Urban Water Resources Management

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PREFACE

Growing population and rising standards of living exert stress on water supply and the quality of drinking water. Some of these pressures can be reduced by demand management and water and wastewater reuse. In wastewater management, new challenges are caused by new chemicals of concern, including endocrine disrupters, pharmaceuticals, hormones, and personal care products, which often pass through wastewater treatment plants unabated, but may cause serious impacts on receiving aquatic ecosystems. Thus, there is a need to address the sources, fate and transport of these new chemicals. Advanced wastewater treatment leads to production of biosolids which are processed in various ways, including on-land applications in agriculture. Again, there are some human health concerns regarding these practices. Municipal effluents, combined with increasing withdrawals of water, lead to the worsening of receiving water quality. This is happening at the time, when the urban population demands water-based recreation and the protection of aquatic ecosystems. Expert opinions indicate that the only way to deal with the current urban water management dilemmas is by integrated management and innovative delivery of water services.

Urban water management issues are particularly important in the countries in transition in Central and Eastern Europe. During the last 15 years, political, economical and social changes in the transition countries have influenced almost every element of the public sector, including water services. In the water sector, there has been a continuing expansion of the role of private companies in the management and operation of water and wastewater utilities, but river basin authorities generally remain under the state control. The process of privatization is accelerated by the lack of capital investments in the public sector and issues of economic efficiency. There is an urgent need for exchange of information among various countries on this issue and for identification of best approaches to managing this transition. Thus, this NATO workshop with its focus on both the countries in transition and the traditional NATO countries should facilitate effective exchange of information and strengthening of co-operation among the experts from NATO, Partner and Mediterranean Dialog countries.

NATO Advanced Research Workshops (ARW) are advanced-level meetings, focusing on special subjects of current interest. This ARW on Integrated Urban Water Resources Management was held in Slovakia under the auspices of the NATO Security Through Science Programme and addressed urban water management problems. It took place at hotel Senec, about 30 km from Bratislava, capital of Slovakia.

The main purpose of the workshop was to critically assess the existing knowledge on urban water resources management, with respect to diverse conditions in participating countries, and promote close co-operation among scientists with different professional experience from different countries.

The ARW technical program comprised 32 papers on 5 topics, Challenges in Management of Urban Water Resources, Challenges in Urban Water Supply, Urban Drainage and Water Bodies, Wastewater Treatment and Security, and Wastewater Treatment and Reuse. Papers addressed a broad variety of issues corresponding to the ARW topics and ranging from reviews and case studies to scientific papers. The organizers hope that the workshop will contribute to improved water management in the regions addressed and thereby to a better security and quality of life.

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CHALLENGES IN MANAGEMENT OF URBAN WATER RESOURCES

PROTECTION OF WATER RESOURCES IN THE SLOVAK REPUBLIC

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Abstract. Water supply resources are groundwater and surface water bodies currently used or intended for prospective use. Water used from identified water bodies shall meet relevant qualitative objectives and resulting requirements on water quality and quantity according to its purpose of use. Water resources protection should be viewed as a integrated protection of quality and quantity of sustace and ground water, including natural curative springs and minerals waters. For water resources protection the protection zones with limited agricultural use and other activities are designated according to the valid legislation. The paper deals with issues relating to water quality and quantity protection.

Keywords: groundwater; protection of water quality; protection of water sources; surface water; vulnerable areas; water sources.

1. Surface Water Quality

Surface water quality assessment is based on the Summarization of the classification results under the Slovak Technical Standard (STS) 75 7221 - Surface water quality classification that assess water quality according to six

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groups of parameters. Proportional grouping of water quality categories at sampling sites of monitored streams is shown in table 1.

During the 2003 – 2004 period the most favorable trends were observed in Group A - oxygen regime where more than 89 % of sampling sites met criteria for suitable water quality, i.e. they met requirements of the quality categories I, II or III. The decrease of sampling sites with required water quality was recorded in the groups of B– basic physical-chemical parameters, C – nutrients and D –biological parameters. In Group B 73,5 % of sampling sites met requirements (2001-2002 period – 87%), in Group C 70,1% of sampling sites were recorded (2001-2002 – 73%) and in Group D only 60,9 % met required quality parameters (period 2001-2002 – 75,8%). The number of sampling sites with required surface water quality has increased in the groups E – microbiological parameters to 19,54 % and F –micropollutants to 54,5 % of sampling sites (2001-2002 – 44,5%).

The most unfavorable situation remains in Group E – microbiological parameters where 80,46 % of sampling sites recorded unsatisfactory category (i.e. included in quality category IV and V). Despite still high proportion of unsatisfactory category it indicates improved water quality (in 2001-2002 - 86% did not meet requirements). Coliform and thermotolerant bacteria caused that the water quality was classified into the category V.

Water quality has been considerably improved also in Group F – micropollutants where 45,4 % of sampling sites recorded unsatisfactory water quality included in quality categories IV and V (2001-2002 –55,5%). Such classification has been done due to concentrations of nonpolar extractable substances and higher aluminium concentrations.

In comparison to previous 2001-2002 period the sampling sites with unsatisfactory water quality has increased in Group B – physical-chemical parameters to 26,4 % and 39,1 % in Group D – biological parameters.

Situation in Group H - radioactivity in monitored period from 2002 to 2003 experienced improved water quality that met requirements of the water quality categories I and II.

2. Groundwater Quality

In 2003, groundwater quality was monitored in 26 important water management regions (especially in alluvial deposits, mezozoic and neovolcanic complexes) at objects of the Slovak Hydrometeorlogical Institute’s network added by wells and used or unused springs. The monitoring network consists of 291 points with monitoring frequency of two times a year.

The groundwater of the "Žitný ostrov" region forms separate part of groundwater quality monitoring in four regions with frequency of 2 up to 12 times a year.

Previous monitoring has proved that there is a problem with unfavorable oxidation-reduction network in Slovakia. In 2003, the groundwater quality was monitored at 46 monitoring objects conditions indicated by frequently present higher concentrations of Fe, Mn and NH_4. The pollution caused by organic substances indicated by frequent exceeding of limit values for concentrations of nonpolar extractable substances (NELuv) and phenols remains the same as in previous years.

The dominant character of land use in monitored areas results in relatively frequent higher concentrations of oxidized and reduced forms of nitrogen in waters.

From the trace elements, higher concentrations were mostly observed in the aluminium concentrations, but together with other parameters they have only local character.

The following groundwater quality parameters measured in situ in the region of "Žitný ostrov" almost at all measuring objects did not meet limit concentrations: dissolved oxygen, in some objects also water temperature (33 measurements), conductivity (9 measurements) and pH (3 measurements). From the group of basic physical-chemical analysis the following parameters had higher concentrations: iron, manganese, ammonium ions, nitrides, nitrates, chlorides, chemical consumption of oxygen with permanganate and fluoranthene as well as phenols and NELuv.

Natural groundwaters are the most important resources of drinking water on the Slovak territory. They represent one of the basic elements of ecosystems. They are used in industry and agriculture. Therefore, it is very important to know their quality within the monitoring of groundwater regime.

In addition to quantitative characteristics, the objective of groundwater monitoring is also focused on:

- assessment of the current state of groundwater quality
- description of ground water quality trends
- providing water management authorities and other entities with basic data
- for decision making process
- application of results to research and expertise activities

Systematic groundwater monitoring within the frame of the National monitoring programme runs since 1982. At the present time, 26 significant water management regions are monitored (alluvial deposits, mezozoic and neovolcanic complexes). For fulfilment of requirements on gathered information about water quality development in regions without considerable anthropogenic effects also pre-quaternary structures were included in monitoring programme.

In 2003, 338 objects were monitored - 210 wells of the SHMI basic network, 38 used and 19 unused wells (exploration wells), 47 used and 24 unused springs. In 2003, the groundwater samples were taken only one time in the autumn.

The results of laboratory analyses were evaluated according to the Decree of the Ministry of Health of the Slovak Republic No. 151/2004 Coll. on requirements on drinking water and control of drinking water quality by comparing the measured and limit values for all analysed parameters. The results are annually published in the "Groundwater quality in Slovakia" Yearbook.

In 2003, the values of acceptable concentration (the highest acceptable concentration) defined by the Decree of Ministry of Health No. 151/2004 Coll. were more often exceeded by the following parameters: Mn (144 times), total Fe (137 times) and NELuv (75 times) from the total number of 338 measurements.

The unfavorable oxidation-reduction conditions indicated by frequently present higher concentrations of Fe, Mn and NH_4^+ pose currently the most significant problem within the groundwater quality assessment process.

As in previous years, the pollution by organic substances indicated by frequent exceeding of the nonpolar extractable substance limit concentrations (NEL_{uv} and chemical consumption of oxygen with permanganate) still prevails. In some monitored regions the number of exceeded NEL_{uv} concentrations has increased compared to previous periods.

The dominant character of land use in monitored areas results in relatively frequent higher concentrations of oxidized and reduced forms of nitrogen in water (nitrides - 30 times, nitrates – 8 times).

As far as trace elements are considered, the most frequent higher concentrations were observed for As (21 times), Al (8 times), Ni (2 times), Pb (1 time) and Hg (1 time). The pollution by specific organic substance has only local character.

3. Water Resources Protection

3.1. PROTECTION OF WATER QUANTITY

The major objective of water utilities is to maximize usage of the stored water resource. In the period between 1989 and 1991, the impact of environmentally uncontrolled exploitation of water-deficit regions was highly adverse, ultimately resulting in the depletion of ground water resources by using the accumulated reserves. As a consequence, water managers, in addition to qualitative water resource protection, began to pay closer attention to quantitative protection, i.e. protection of the volume of water reserves.

The water resources protection in Slovakia is considered as an integrated protection of groundwater and surface water quality and quantity, including springs and mineral waters. Quantitative protection is based on accumulation ability and management of particular region with respect to abstracted or pumped water. This is the reason why the limit for surface water use is determined by so-called ecological limit (MW_{eko}), which has no effect on a habitat in river basin.

The quantitative protection of the yield of ground water was introduced in 1993. At the same time, the Methodology of Establishing Ecological Limits of Ground Water Resource Utilization was developed and applied in the General Protection and Rational Water Utilization. The methodology defines how to establish usable volumes of ground water resources while ensuring sustainable development of the land by defining general ecological limits for the entire watershed – a hydrogeological zone or hydrogeological structure, as well as local ecological limits for particular sources that are being used (springs and wells). Previous experience shows a decrease in the volume of continuously used springs Qmin and wells Qrec of 15-20% and 20-30%, respectively.

Qualitative protection plays significant role in water resource quality protection. The pollution comes from population, industry and agriculture through various types of contamination. Legislation determines obligations and responsibilities for wastewater discharge and manipulation with chemicals in order to avoid deterioration of surface and ground water resources.

3.2. PROTECTION OF WATER QUALITY

One of the key roles of water protection in terms of water quality is to resolve the problems relating to sources of pollution. Pollution sources, which have a negative impact on water quality, are broken down into two categories based on the type and severity of their impact: *point* sources of pollution and *non-point* sources of pollution.

The most significant *point sources of pollution* are wastewater discharges from industrial and agricultural facilities and from residences. Even though the volume of discharged wastewater has been declining since 1990, in order to ensure active water quality protection, the portion of population connected to the sewage system has to be increased and measures relating to wastewater treatment have to be taken.

Legally, the polluter is in charge of drainage water and sewerage treatment and obliged to monitor the quantity and quality of discharged wastewater. The validity of monitoring results depends on the precision of the sampling procedure and the level of expertise of laboratories providing wastewater analyses.

The currently operated wastewater treatment plants represent a specific problem, because they are overloaded (both hydraulically and from a load point of view) and the wastewater treatment technology does not comply with legal regulation standards any more.

Four protected areas are determined according to the Act No. 184/2002 Coll.:

1. Protected water management areas (PA)
2. Protection zones of water supply resources (PZ)
3. Sensitive areas (SA)
4. Vulnerable areas (VA)

3.3. PROTECTED WATER MANAGEMENT AREAS

The government is allowed to designate protected water management areas in the case when they form with their natural conditions an important region of natural water accumulation.

All activities in protected water management areas can be planned and performed only if a broad protection of surface and ground water will be assured. The protection of water production, occurrence as well as transport and other interests shall be in accordance with requirements set for protected water management areas within the processing of development conceptions and regional planning documentation.

Today, there are ten designated protected water management areas in Slovakia covering area of 6942 sq km that represents 14, 2 % of the entire Slovak territory.

3.4. PROTECTION ZONES OF WATER SUPPLY RESOURCES

Protection zones of water supply resources are designated by the state water authorities with aim to protect their yield, quality and safety.

Protection zones of water supply resources are divided into the protected zone of the 1st degree serving for its protection in direct vicinity of water abstraction points or capture devices and the 2nd degree protection zone serves for protection of water supply resource against risks coming from more distant sites. For enhanced protection the water authority is allowed to establish also the 3rd degree protection zone.

If conditions in the locality of the 1st degree protection zone provide sufficient protection of water resource yield, quality and safety, further degrees of protection zones will not be designated.

Designated protected zones serve simultaneously as the sanitary protection zones (SPZ) defined under the specific regulations.

According to 2002 data there are about 1138 SPZ groundwater resources in Slovakia. A single SPZ, especially the 2nd degree SPZ, may comprise several water resources, e.g. the entire spring line or group of wells, etc.

TABLE 1 The area of Slovakia covered by the water resources protection zones

Type of resources	Number	Area of PZ	% of Slovak territory *
Groundwater resources	1131	3562 sq km	7,26
Surface water resources	71	5051 sq km	10,30
Total	1209	8613 sq km	17,56

* Slovakia covers area of 49 034 sq km.

TABLE 2 The water supply protection zones in Slovakia

No.	Name of water Reservoir	(sq km)		
		TOTAL	AGRICULTURAL LAND	FOREST AREA
1.	Bukovec	52,9	5,12	45,91
2.	Hriňová	71,04	9,61	60,97
3.	Klenovec	92,12	26,9	65,22
4.	Málinec	78,72	33,46	44,17
5.	Nová Bystrica	59,32	5,39	53,13
6.	Rozhund	3,42	0,47	2,89
7.	Starìná	120,45	4,99	115,46
8.	Turček	28,96	-	28,96
	TOTAL	506,93	85,94	416,71

In Slovakia there are 73 SPZ intended for surface drinking water abstraction, of which 8 are related to abstraction from water supply reservoirs and 65 SPZ are designated to direct abstraction from surface streams that are situated mostly in the East Slovakia Region. The area of Slovakia covered by the water resources protection zones is listed in Table 1. Since the water supply resources protection zones cover the largest area of all water resources, they are listed for illustration in the Table 2.

The above-mentioned data indicate high percentage of the area covered by protection zones in Slovakia – 17,56 %. It is important to note that the areas of protection zones of some water supply resources arte often overlapping. Therefore, the area of 17,75 % does not represent the total area of protection zones in Slovakia, but it is a sum of all individual protection zone areas without mutual overlapping. After consideration of the zone overlapping, the area of all protection zones covers 3 113 sq km in total, i. E. 6,36 % of the Slovak territory.

3.5. SENSITIVE AREAS

Sensitive areas are surface water bodies, water quality of which is or can be threatened by increased nutrient concentrations; which are or can be used as water supply resources as well as water bodies requiring a higher level of discharged wastewater treatment with regard to advanced water protection interests.

In 2003, the Governmental Regulation specifying designation of sensitive and vulnerable areas came into force. All surface water bodies in Slovakia have been declared as sensitive areas.

3.6. VULNERABLE AREAS

Vulnerable zones under the Water Act are agriculturally used areas where rainfall water flows into a surface water or infiltrates to groundwater resources in which the nitrate concentration is higher that 50 $mg.l^{-1}$ or can be exceeded in the near future. Plots agriculturally used in particular cadastral territories listed in the Governmental Regulation have been designated as vulnerable zones. In particular, it relates to all lowland areas of Slovakia, alluvial plains of larger rivers as well as lower situated valleys with agriculturally used land.

Sensitive and vulnerable area identification is being re-evaluated every four years under the coordination of the Ministry of Environment of the Slovak Republic.

The Regulation accepts the possibility to not declare the 3rd or even 2nd degree PZ of water supply resource, if there exist other type of area protection, e.g. vulnerable area. In practice it means that such protection can substitute the function of the 3rd degree PZ and in specific cases even the 2nd degree PZ.

In addition to the above, there exist six categories of protected areas with various protection levels in Slovakia. Within the national system of protected areas there are currently 23 large protection areas in Slovakia – 9 national parks and 14 protected landscape areas covering 1 113 565 ha (including protection zones) and 1 101 smaller protected areas – 385 nature reserves, 228 national nature reserves, 239 natural monuments, 66 national natural monuments and 189 protected natural ranges with the total area of 111 062 ha (including protection zones).

In addition to the above categories, Natura 2000 the new integrated European system of protected areas is now being prepared in Slovakia. It is also included in the Act on protection of nature and landscape. The system of Natura 2000 is based on the two EU Directives that represent the most complex legal standard for natural protection in the world so far.

4. Conclusion

Monitoring of water resources qualitative parameters has a long-standing tradition in Slovakia. Issued legislative regulations define parameters and character of quality monitoring as well as number of analyses in relevant monitoring periods. The above results indicate that quality of our water resources becomes slightly better. However, there exist some water resources with water unsuitable for long-term drinking water abstraction. Following the EU legislation, the lower profile trend occurs also in Slovakia, but I consider it as a negative trend.

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STS 757221 surface water quality classification

THE HUMAN DIMENSIONS OF IWRM: INTERFACES BETWEEN KNOWLEDGES AND AMBITIONS

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Abstract. The challenges of IWRM are multiple and practitioners are only recently starting to come to terms with some of the implications of the theory. In promoting wider consultation and involvement in the management of water resources, IWRM approaches encroach on the worlds of social relations, governance and politics. In this paper, we argue for more investment in understanding how competing knowledges and ambitions might influence the search for effective and just water management arrangements. Through discussion of the nature of the interfaces where such competition takes place and the constraints placed on praxis by theory, we expose a number of challenges for the academic and practitioner communities.

Keywords: IWRM; knowledge; human dimensions

1. Introduction

The maxim that ‘water is life’ can not be considered a cliché, but is rather a reality and a statement of fact (Kgarebe, 2002). Water is a habitat, a life supporting resource, a means of production and transport, and a commodity. Water flows, it has geographic mobility. Changes in water quality or flow at one end of a catchment can impact river characteristics downstream; resulting in the translation and transmission of attributes across time and space. Water is international, national, regional and local. The complexity and interdependence

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of the water environment network presents particular problems for management.

Hydraulic capacities have been the hallmark of organised social systems throughout history (Fernandez-Armesto, 2000) and typify modern political economies. Linked implicitly with the paradigm of rational planning, assured water supply has underpinned the policy objectives of centrally managed public health, food security and hence economic development. This has placed the water sector, along with transport and energy, as one of the key infrastructural requirements of any modern society. Water supply is thereby locked chronologically with urbanisation, intensive agriculture, industrial economic development, central planning and the development of the modern nation state. The recognition that water plays a central role in industrial, agricultural, economic, social and cultural development has, over the past half century, led to the development of strategic management approaches based on the concept of Integrated Water Resources Management (IWRM).

2. What is IWRM?

IWRM has been advocated as the most sustainable means to incorporate the multiple competing and conflicting uses of water resources ever since the first UNESCO International Conference on Water, which took place in 1977 at Mar del Plata, Argentina. IWRM operates within a closely defined arena in developed economies, its trajectory mirroring the rise and fall of the 'hydraulic mission' (Reisner, 1986). As IWRM became a necessity, as managing political economies became more complex, so the advent of post-industrial societies and growing water stress revealed a lacuna in the ability of IWRM's demand management approaches to tackle the phenomena of water stress.

The Global Water Partnership (GWP) defines IWRM as 'a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.' (GWP-TAC, 2000). Whilst there have been suggestions for modifications to this designation (Jonker, 2002), the GWP version remains the most oft quoted version. As an ambition, IWRM therefore seeks to address (simultaneously!) two highly complicated and complex problem sets; sustainable development and cross sectoral planning.

Perhaps the clearest way to put some detail on this idea of IWRM as a complicated and complex problem is to refer to the work of Rittell and Webber on 'Wicked Problems' (Rittel and Webber, 1973). Amongst the ten characteristics of such problems proposed by these authors, the following are of particular interest here. Wicked problems;

- have no definitive formulation
- have no true-or-false / right-or-wrong answers, only good-or-bad ones
- do not have a well-described set of potential solutions. Various stakeholders will have differing views of acceptable solutions.
- are essentially unique. There are no 'classes' of solutions that can be applied to a specific case.
- can be explained in numerous ways. There are many stakeholders who will have various and changing ideas about what might be a problem, what might be causing it, and how to resolve it.

'Solving a wicked problem is fundamentally a social process. Having a few brilliant people or the latest project management technology is no longer sufficient.' (Conklin, 2005)

3. The Human Dimension Characterised

So how do human beings fit in to IWRM? Water is characterised by the United Nations as a 'primary good' (The United Nations Declaration on Human Rights -Article 25/1 adopted by the U.N. General Assembly in 1948 without a dissenting vote), and as such it has a special and vital relationship with our societies. Primary goods can be defined as those commodities which human beings require for survival. Water availability and quality are significant influences on our health and well-being, our economy, our environment and our daily lives. Hence effective and sustainable water management requires an understanding of the various relationships between water (as both commodity and natural resource) and the social, economic, technological, and environmental contexts in which it is exploited.

Whilst new processes, technologies, legal and economic tools, and management frameworks are key components of a secure water future, their development and application needs to be informed by consideration of the role of water in society. Attitudes and behaviour will be influenced by many factors including the details of individual and community recent experience, culture, history, and economic / technological development. This creates a complex and often unstable environment within which water management agencies try to plan and operate.

Whilst I don't doubt that most people could identify a set of forms of relationship between water and human societies, there is one particular feature of this relationship which has special significance for IWRM. As well as being actors in the IWRM process, communities are also acted on. They are both the architects of remedial plans and the beneficiaries or victims of such plans. Similarly, in many cases, human communities are both the cause and resolution of the problem, a source of knowledge and the users of such knowledge. And it is within these dualities that we encounter the primary issue of this paper; human ambitions drive the manipulation of the water environment but these aspirations are often frustrated by the heterogeneous nature of our societies.

Our communities are becoming increasingly socially diverse in terms of their ethnic, cultural and religious makeup. The institutional networks responsible for knowledge creation and exploitation are becoming increasingly specialised and numerous. Despite the creditable efforts of many people to promote more effective integration and engagement, and wider participation in the water sector, we are still faced with the challenge of bridging interfaces and resolving the tensions between the general (principles, justice, knowledge) and the specific (problems, circumstances, people).

4. Interfaces

Much of the 'engagement' that is talked about in IWRM occurs at the interfaces between science, community, and governance. Interfacial processes will involve an attempt to bridge or integrate knowledge, experience and opinion across scientific, societal and governance communities. In the context of IWRM, representative examples will include the preparation of basin management plans, the deployment of new technologies, and the allocation / distribution of water resources. Far from being simply notional boundaries between sets of actors in society, these interfaces are characterised by significant discontinuities. Specifically, human interaction at an interface is likely to involve disagreement concerning;

- sources of credible information and plausible knowledge on which to base action
- the value and valuation of products and processes
- acceptable risks
- temporal and spatial relevance of knowledge
- notions of efficiency and effectiveness

If IWRM is to live up to its billing as 'Integrated' then the format, tempo, and significance of processes occurring at these interfaces need understanding and management.

But what happens at these interfaces? In simple terms, we can characterise relevant interactions as goal directed, involving;

- dispute the (nature, meaning, ownership etc.) of the problem
- debate about the reality of the problem for different actors
- negotiation of possible solutions and what constitutes a 'better outcome'
- anticipation of the impacts of solutions
- planning changes to steer our communities along better development paths

Interfaces are clearly scenes of dialogue, analysis. deliberation and debate (Guimãres Pereira *et. al.*, 2003). In particular, they host negotiations between differing interpretations of problem diagnosis and resolution. They are arenas where personal, social, and professional ambitions clash, and where competing models of 'what is' and 'what to do' are articulated.

To take one example of the type of interface we are interested in, let us consider that between science and politics. Most scientists are concerned about single issues or phenomena and, correspondingly, the idea of "solutions". The policy world, on the other hand, exists in a multiple-issue and multiple-constituency world where the agenda is constantly changing and where an environmental issue is only one of many competing for attention

There is an additional problem of diagnosis. Scientists and other environmental specialists (water companies, technical professionals in local or regional government and so on) simplify from complex situations in a way that enables them to apply their knowledge. We have come across numerous situations where the interpretation of the symptoms of an environmental disorder have been specified as very different "problems" by politicians and specialists and between specialists themselves. A simple example is a situation where more water is being consumed than can be sustained in a local environment: in one domain, the problem may be perceived as excessive water use, but in another, it may be perceived as insufficient supply. The policy implications of the two perceptions are dramatically different, in that the first would result in a policy instrument to reduce water consumption, whereas the second would result in a technical solution that would increase water supply.

This mismatch of agendas and "problem" identifications can result in inappropriate research, perhaps because it is not at a suitable scale or cannot easily be connected to decision issues. Conversely, relevant research may just not be important to people who consider many other issues to be more significant at that time.

So, to briefly recap;

1. IWRM is a 'wicked' problem, being both complicated (many elements interacting in many ways at different spatial and temporal scales) and complex (as above but with the added dimension that the rules or laws by which interaction takes place are also changing … so any specification of the relationship between phenomena 'A' and phenomena 'B' will change through time).
2. In attempting to design and implement IWRM strategies, society is faced with the challenge of negotiating and operating across many types of institutional and knowledge interface.

It is negotiation (at the various interfaces) of different ways of understanding the problem and modes of intervention that we wish to focus on for the remainder of this paper.

5. What Sort of Cow is it?

If we accept that our problem set (IWRM) is both complicated and complex, are there any ways of understanding the process that can help us make sense of it? Researchers have, of course, evaluated many different conceptual frameworks and conceptual models in search of a coherent and consistent method for diagnosing water management issues and prescribing beneficial intervention. This has included work on IWRM itself (Biswas, 1981) but also contributions from Systems Theory (Votruba, 1988), System Dynamics (Stave, 2003) and Adaptive Management (Walters, 1986).

Some utility has been claimed for all these approaches. Although such limited success is welcome from an ontological perspective, within a world of wicked problems, it leaves us with a problem. Put simply, the model or interpretational framework that we use to describe something will influence how we seek to influence its future.

Let me use a simple analogy to make the point. We can consider a cow as performing a multitude of functions. It can produce milk, meat, hide, and more cows. The optimum management regime for our cow will be determined by how we understand it, or want it, to behave. The way we intervene in our cow's daily existence will depend on whether we wish to enhance its potential to deliver milk, meat, hide, or more cows! Problems arise when our bovine production system fails to behave in accordance with our descriptive model or we wish to change our aspirations for the cow. A 'wicked' cow may start bleating like a sheep and we may wish to change the benefit we get from the cow from meat to milk. And if we do want to optimise milk production instead of meat production, do we need new knowledge and understanding of our cow?

To return to the case of IWRM, water environments provide multiple functions to multiple communities. Both functions and communities change across space and time. Each community or stakeholder group will have a preference for a set of functions and a preferred interpretive model for describing / diagnosing the system. Each potential use, perspective or way of understanding will have its adherents (disciplines, professions, stakeholders etc). Although theories of change such as systems dynamics or coevolution promise generic or integrated understanding, they still lock us in to a way of managing the resource which is dependent on how we understand it to work

Prescription and intervention is a function of diagnosis or understanding. Economists run something called the economy, engineers do engineering. An integrated or holistic insight can't give us anything better than policy guidance based on creating a more efficient or effective integrated or holistic system …. and we know that systems with these characteristics are often unpredictable, unstable, unjust, and unmanageable.

6. Conlusion

The foregoing text is somewhat belligerent in style. The objective has been to promote debate, raise questions and explore the implications of wider public involvement in natural resource management. One hope's that readers do not gain the impression that a case is being made for a particular form of knowledge or ambition to be priviledged over others. Subjective and objective interpretations of experience are not incommensurate. Reliable knowledge of the natural world (e.g. physics) and time-limited knowledge of particular phenomena (e.g. human behaviour) are of equal value in forming a useful picture of the human condition. It is not our intention to belittle either tradition. The problem here is one of accommodation. The knowledges and ambitions cited in the title of this paper are both absolute and relative, general and specific, personal and social, rational and seemingly foolish.

As the franchise for involvement in water resources management has been extended, so the variety of perspectives, beliefs, aspirations, and understandings which impinge on the IWRM debate have mushroomed. Our concern is that this variety of (often strongly held) ways of understanding the world should not prevent the fair and just management of the resource. Simply expecting interaction, engagement, participation, and dialogue to magically generate widely acceptable outcomes is a risky strategy. Our immediate experience is that the expected benefits of wider participation are often transitory and costly to achieve.

Does there need to be agreement about the way the world works or the value of the resource in order for catchment communities to agree on a management scheme? Do we need orthodox ontologies and epistemologies in order to manage the resource for the benefit of all?

Until we understand more about the implications of competing claims to understanding and knowledge, we will be unable to respond to such queries. Perhaps our mistake is to act as though accommodation is possible?

Acknowledgment

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SUPPORTING THE SITING OF NEW URBAN DEVELOPMENTS FOR INTEGRATED URBAN WATER RESOURCE MANAGEMENT

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Abstract. Establishing the best location for new urban developments requires a synthesis of a variety of factors that, in view of sustainability principles, need to encompass technical and environmental issues related to urban water as well as broader requirements related to the economic and social characteristics and constraints of the region. The complexity of the problem requires a concise, structured and objective method of data organisation and analysis. Decision support systems (DSS) provide such a framework, aided by the incorporation of multi-criteria analysis. This chapter details the development of a DSS tool, based on a fuzzy inference methodology, able to prioritise areas suitable for new urban areas and to screen out unsuitable sites. The effectiveness of the tool was tested on the Humber sub-region in the UK. Results suggest that the overall suitability evaluation is mostly influenced by the choice of site attributes taken into account and to a lesser degree by analytical processes. It is concluded that the tool is flexible and user friendly and can significantly assist in the assessment and visualisation of the effect of spatial characteristics and user preferences on the siting of new urban developments.

Keywords: decision support systems; GIS; multi-criteria analysis; screening tools; sustainable development

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1. Introduction

The work presented here forms part of the on-going WaND research initiative in the UK aiming towards the implementation of sustainability principles in the planning of new urban developments (Makropoulos *et al.*, 2005). Planning for sustainable urban development at a regional scale needs to encompass issues related to the environment, economy, size, location, economic and social growth of a region. As such, land use planning requires the collection, analysis and investigation of interactions between disparate types of information. Screening and site prioritisation decision support tools can serve as a means to formalise and automate this process identifying areas that satisfy specific criteria and assessing the uncertainty inherent in such an analysis. Sustainability criteria can be quantified through the use of indicators, including the SWARD indicators developed for the water industry (Ashley *et al*., 2004), thus becoming "operational" through the screening tools.

This chapter addresses sustainability issues related to urban development through the selection and "operationalisation" of relevant criteria. Issues of site prioritisation and selection are examined and cross-referenced with existing planning policy and water management regulations in the UK. The paper presents the development of a decision support tool, enabling the screening and prioritisation of sites at a regional scale and tests the tool by applying it to a specific study area. The results of the case study are an indication of the tool's satisfactory performance and sensitivity to different development scenarios and user profiles.

2. Decision Support in Land Use Planning and Regional Development

The role of decision support systems in the field of land development lies in supporting and strengthening the process of choice and their development has been associated with the development and rapid uptake of information technology (Sprague, 1980). The DSS' range of applications in the fields of land development, environmental and land use management is extensive and was recently expanded to include issues of sustainable development. Examples of current research related to the latter include Tiwari *et al.*, 1999) who developed a decision making process for the incorporation of sustainability criteria in lowland irrigated agriculture. Nauta *et al.* (2003) created a DSS to aid sustainable development in Laguna Bay, Philippines. GIS, hydrological, water quality and waste load models were used to review and produce economically and technically feasible options for sustainable development at catchment scale. Armstrong *et al.*, 1991) addressed the problem of finding optimal service locations within a region by developing an SDSS. This system solved for multiple objectives related to minimising the average distance from clients to central facilities. Zhu *et al.* (1996) discuss the design and application of an SDSS called ILUDSS (Islay Land Use Decision Support System) for strategic land use planning in Islay, Scotland. The system combined analytical, rule based and spatial models to form a knowledge-based system for the assessment of land use potential. To achieve the latter, the authors examined criteria associated with physical suitability, proximity to key locations and area of land parcels. Thomas (2002) examined the development and application of a decision support system that enables site screening on a national basis. The system incorporated and analysed information from existing state, regional and local geospatial databases, GIS based visualisation models and spatial analysis and public interaction. The above list, although clearly not complete, serves as an indication of the growing interest into operationalising sustainability within the land use and regional planning domain.

3. Sustainability in New Urban Developments

Sustainable development in the context of water resource management is achieved by minimising the impacts of new urbanisation on the catchment as a whole. Cities play an important role in upsetting a catchment's equilibrium by acting as both sinks of resources and sources of pollution (Makropoulos, 2003). Cities induce a significant demand on water resources especially considering the growing rate of urban population and water use. The introduction of impermeable surfaces, the reduction of stormwater infiltration rates and increase in surface runoff, coupled with diffuse pollution originating from wastewater are simple examples of the impact of urban developments. On the other hand, the presence of poor water quality can adversely affect urban regeneration and quality of life.

Clearly, the impact of traditional urban developments and the conditions they introduce are opposed to the goals of sustainable development. However, modifications in conventional urban planning towards more explicit (and formal) incorporation of sustainability at the earliest possible stage may lead towards more sustainable solutions, alleviating part of the problem.

Operationalising sustainability is a difficult and ambiguous process and the approach adopted here is the selection of appropriate criteria linked to specific indicators. A criterion represents a measure against which option performance is assessed along with the degree to which stated objectives are achieved. Indicators constitute a means of measuring the level to which criteria are satisfied. The criteria-indicators approach adopted in this work, relates to the framework developed within the Sustainable Water industry Asset Resource Decisions (SWARD) project (Ashley *et al.*, 2004), which focuses on sustainability for the water industry as well as sustainability principles incorporated into the UK planning regulations.

4. Development of a Decision Support Tool

4.1. FRAMEWORK

A framework was developed to enable the structuring of a decision support tool to assist a sustainable site selection process. The framework links diverse elements of the decision process, including articulated objectives, criteria and indicators as well as decision makers' preferences. The selection process is formalised into a series of successive steps. A schematic representation of the framework is provided in Figure 1.

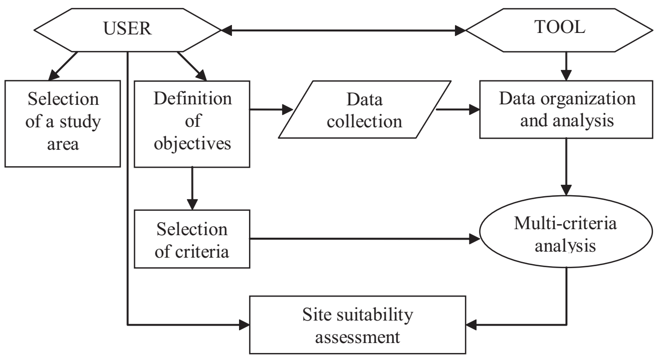

Figure 1 The decision support framework

4.1.1. *Definition of objectives*

The overall aim of the decision support system is the selection of the most suitable sites for sustainable urban development. To achieve this, a number of specific objectives must first be specified. The definition of objectives involves the selection of sustainability criteria that are directly related to specific indicators, which in this case consist of the (spatially variable) attributes of the areas at a regional scale. The sustainability criteria and associated indicators used in this work are outlined in Tables 1, 2 and 3.

4.1.2. *Selection of a study area*

Once the objectives are defined they can be applied to a specific geographical area. The study area's size must be large enough to support new urban developments and therefore the tool is best applied at a regional scale. The area under consideration is chosen by the stakeholders. Its features and development history must be carefully reviewed in order to provide the necessary context to the sustainability criteria.

TABLE 1 Environmental sustainability criteria and indicators

	Criteria	Indicators (Spatial Attributes)
General	Impact on sites of ecological and environmental significance (PPG 9).	Location of sites characterised as SSSI, SAC, SPA, RSAR, NNR, sensitive waterway or ancient woodland. Distance from sites of ecological and environmental significance
	Influence of new development on established land use.	Location of existing land use sites.
	Impact on countryside and urban regeneration (PPG 3)	Location of brownfield sites Location of greenfield sites.
Ground water	Groundwater quality and recharge and abstraction areas	Distance from source protection zones
	Development near vulnerable aquifers (WFD)	Location of areas with sustainable abstraction status
Surface water	Impact on nutrient sensitive areas (Urban Waste Water Treatment Directive (1/271/EEC))	Location of nutrient sensitive areas
	Impact on natural stormwater drainage patterns (Stormwater management and design manual)	Distance from streams

4.1.3. *Selection of criteria and indicators*

The scope of this work does not include the entirety of issues pertaining to sustainable development. Rather, the main focus is on urban water resource management. As such, a large number of criteria are related to water (ground and surface) quality and resource management; although a number of general siting constraints must also be adhered to. The criteria set is outlined in Tables 1- 3.

The process of determining site suitability is rendered transparent through selection of appropriate sustainability criteria associated with specific indicators (in the form of spatial attributes). Sustainability criteria are directly related to planning policies (e.g UK National Planning Policy and Planning Policy Guidance notes (PPGs), the Water Framework Directive (2000)), the water industry (e.g. the SWARD project (Ashley *et. al*, 2004) and work from Water UK (2000)) and the scientific literature (e.g. Eurostat (1999), the Organisation for economic Cooperation and Development (1998), the United Nations (1996)).

TABLE 2 Social sustainability criteria and indicators

Criteria	Indicators (Spatial Attributes)
Gap between the poorest communities and the rest (PPG3)	Location of most deprived communities in the UK according to the index of total deprivation
Social isolation and socio-economic inactivity (PPG 13)	Distance from urban centres and trade activity zones

TABLE 3 Economic sustainability criteria and indicators

Criteria	Indicators (Spatial Attributes)
Cost of site development	Ground slope
Ease of transportation (PPG 13, PPG 3)	Proximity to transportation nodes and branches
Access to safe drinking water	Proximity to reservoirs, abstraction wells and water supply networks
Flood risk. Selected sites must be included in flood zones 1 and 2 (PPG 25)	Distance to flood plains

4.1.4. *Data collection and analysis*

In order to provide the user with the raw material for the analysis, a number of spatial, georeferenced data types must be selected and incorporated into the decision making process. Site related data include:

1. Topography: elevation and water bodies
2. Transport infrastructure (road, railways, waterway access to site)
3. Floodplain characteristics

4. Current land cover (forest, wetlands, fields)
5. Estimated number of residential, commercial, industrial facilities
6. Building and population density
7. Land use and land use types: Urban, industrial, agricultural
8. Site ecology
9. Freshwater sources: Surface and groundwater
10. River and stream quality
11. Aquifer source protection zones
12. Location of landfills

4.1.5. *Multi-criteria analysis (MCA)*

Within the system developed here, data are handled in the form of GIS raster files, structured in a series of rows and columns, forming cells. Each cell has its own properties, linked to various physical and geographical attributes and can be considered an "alternative" in the context of site suitability assessment, in that it potentially represents a solution to the siting problem (Malczewski, 1999). A raster map can therefore be considered as the spatial representation of a large number of alternatives. Multi-criteria analysis is used to achieve the selection of the best alternatives based on consistent application of expert judgment and user preferences. The criteria incorporated are used to a) narrow down the number of alternatives through a screening process, b) evaluate the remaining cells in terms of their suitability/sustainability.

Criteria are divided into "crisp" and "fuzzy". Crisp criteria, also referred to as hard constraints, differentiate the areas where development is feasible from those where it is not. Such constraints are also called Boolean and for the purposes of this paper reflect the inability to develop in certain areas. The areas that are screened out due to Boolean constraints include sites of established land use, environmental significance or large water bodies. The rest of the criteria are treated as fuzzy. In practical terms, each fuzzy criterion is linked with a relevant indicator (spatial attribute) attribute associated with a set of fuzzy inference system (FIS) rules (see for example, Makropoulos *et al*. (2003)). The input data at a cell-by-cell scale is then analysed via the FIS to provide suitability outputs for each cell. This process is repeated for every criterion resulting in a set of different suitability values for any given cell. A weight is then attached to each criterion depending on its (user specified) importance. Aggregation of the criteria yields a value for each grid cell, representing its overall suitability. The users can customise the MCA process by creating and applying their own scenarios. Scenario variability can be expressed in terms of selected criteria and weight assignment. Sensitivity analysis can thus be performed to quantify the impact of different choices to the final outcome. By ignoring certain criteria and placing more importance on others, users can focus on different aspects of sustainability and assess their impact on the siting of alternative urban development schemes.

4.1.6. *Site suitability assessment visualisation*

Finally, the tool facilitates the presentation of the results of the spatial multi-criteria analysis. Cells containing similar suitability values are grouped together and classified accordingly, thus defining the optimum sites. The results from multiple scenarios and sensitivity analysis can be evaluated individually or in relation to each other. The latter prospect gives an indication of the best or worst case scenario or gauge the effect of different approaches to urban development, facilitating the decision making process.

4.2. SYSTEM ARCHITECTURE

The tool consists of four modules:

1. A spatial analysis and information generation module: ESRI's ArcView GIS acted as the main tool for data storage, organisation and analysis. Through it, raw data, usually in vector form (shapefiles), is organised into map layers, analysed by GIS operations and discretised into raster grid cells. Through GIS analytical operations, raw data is converted into information related to spatial attributes that can be used in conjunction with the sustainability criteria set.
2. A graphical user interface: MS Excel was used as the main user interface (GUI). The GUI allows the decision maker to change the criteria taken into account as well as the importance between criteria/factors. For this reason, it incorporates three methods of criteria weighting: ranking, general ranking and equal weights. Integration between this module and the MCA and screening module developed in MATLAB was accomplished using Mathworks ExceLink™ add-in.
3. Multi-criteria analysis and screening module: This module combines the information generated from other parts of the SDSS and performs multi-criteria analysis using fuzzy logic as the mathematical basis for its computational algorithms. The programming routines performing multi-criteria analysis were written in MATLAB. Raster based information related

to the various physical attributes is converted into ASCII files and imported into this module in order to undergo MCA. Using a fuzzy screening technique, alternatives can be evaluated in terms of linguistic variables with respect to specific attributes, presented in a non-numerical scale. Attribute input values can be referred to as, for example, "low", "medium" or "high". Each of these classifications is represented by a fuzzy membership function. The same apples for the output suitability ranges which are also classified as "high", "medium" and "low". Sustainability criteria are used to link inputs and output through "IF…THEN" rules. Suitability output values range within the continuum from 0 to 1, where 0 represents the lowest or unsuitable option and 1 expresses the highest suitability. The module then performs criteria weight assignment and aggregation according to the method chosen by the user. Hard constraints are then applied to limit the decision space and the final result is a map containing cells of varying suitability for new urban development siting at a regional scale.

4. A result presentation module: The final result derived in the previous module is imported into the GIS environment and converted into a raster grid. Through this process, the evaluation of each alternative becomes visible as a GIS map. Areas can be defined in terms of increasing suitability using a reclassification operation. The areas denoted by the highest-ranking cells receive primary status in the site selection process.

5. Case Study: The Humber Sub-region

The tool was applied to the Humber sub-region in the UK. This sub-region covers an area of 3,517 km^2. Its population for the year 2002 was estimated to be 870,600. It is an area rife with geographical and socio-economic diversity. The area supports a wide range of economic activity, though contrasts exist between the socio-economic welfare of its different parts. The Humber estuary is the sub-region's characteristic physical feature and potential source of economic development. It provides the area with a major trading outlet towards Europe and the adjoining UK regions. The city of Hull acts as the sub-regional capital and is the primary economic, civic and cultural centre.

5.1. SUB-REGIONAL SUSTAINABILITY ASSESSMENT

To explore the functionality of the decision support system developed and its capability to support users with different objectives and prioritisation, a scenario approach was adopted. Two scenarios were set up representing users with different "agendas". The primary assumptions of these scenarios and the results of the ensuing analysis are described below. The criteria used in the analysis are listed in Table 4.

5.1.1. *Scenario A: Supporting the aims of regional planning guidance*

Careful study of the UK Regional Planning Guidance (2000) and the UK Regional Sustainable Development Framework (2003) for Yorkshire and the Humber indicates a number of attributes within the case study area that can be related to some of their aims and objectives. These formed the basis of the multi-criteria analysis. The planning guidelines suggest the following order for the attributes: 2, 7, 5, 12, 6, 10.

TABLE 4 Analysis criteria

1	Ground slope
2	Distance from transportation networks
3	Distance from flood risk areas
4	Distance from freshwater sources
5	Distance from sites of environmental significance
6	Distance from derelict and brownfield sites
7	Groundwater availability
8	Nutrient sensitive areas
9	Distance from surface water bodies
10	Social inclusion
11	Distance from urban areas
12	Distance from trade activity zones

Clearly, different rankings and resulting weighting methods can be used, subject to the user's needs and judgement. The result of this particular combination of criteria and weighting methods is the suitability map that is displayed in Figure 2. The suitability ranges indicate the influence of the high-ranking criteria such as groundwater availability. The area located on the aquifer section where water is still available receives the largest suitability values (0.65-0.8). The criterion that demands proximity to transportation networks also plays an important part in the final result, especially in the more remote parts to the north of the study area. The areas situated to the south of the Humber estuary are on average more suitable in comparison to the north bank. This is as a result of the south part of the region being located in the Humber Trade Zone, while the north part features many areas of environmental significance.

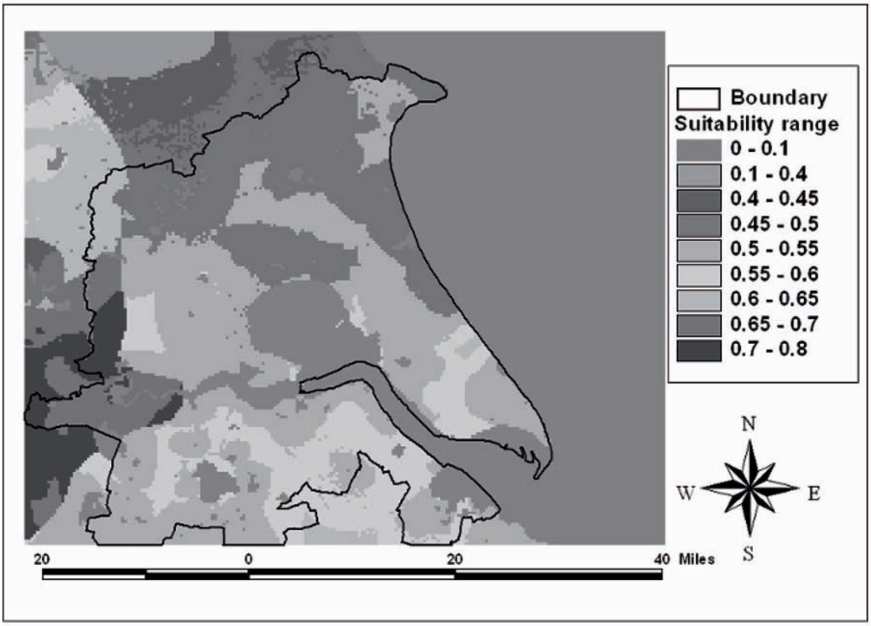

Figure 2 Sustainability map for scenario A

5.1.2. *Scenario B: An eco-centric approach*

The previous approach overlooked important aspects such as proximity to surface water sources, drainage patterns, nutrient sensitive areas and flood risk. This scenario attempts to examine the effects of prioritising for the environmental aspects of sustainability. The approach was undertaken using the general ranking weight assignment method. Environmental related attributes received the greatest importance factor, succeeded by economic and then social. Again it should be noted that this approach is not the only one. For example, economic and social criteria may receive the same medium or low importance. The resulting suitability map is depicted in Figure 3. The zones of highest suitability are formed of cells whose values range from 0.6 to 0.65. These areas coincide with zones of groundwater availability. The lowest suitability (0.3-0.4) is found in steeply sloped areas. The remaining area is characterised by average to poor performance (0.4-0.5). The generally average suitability values are attributed to the fact that most environmental criteria pose restrictions to development. Therefore, the prioritisation of environmental factors reduces overall suitability.

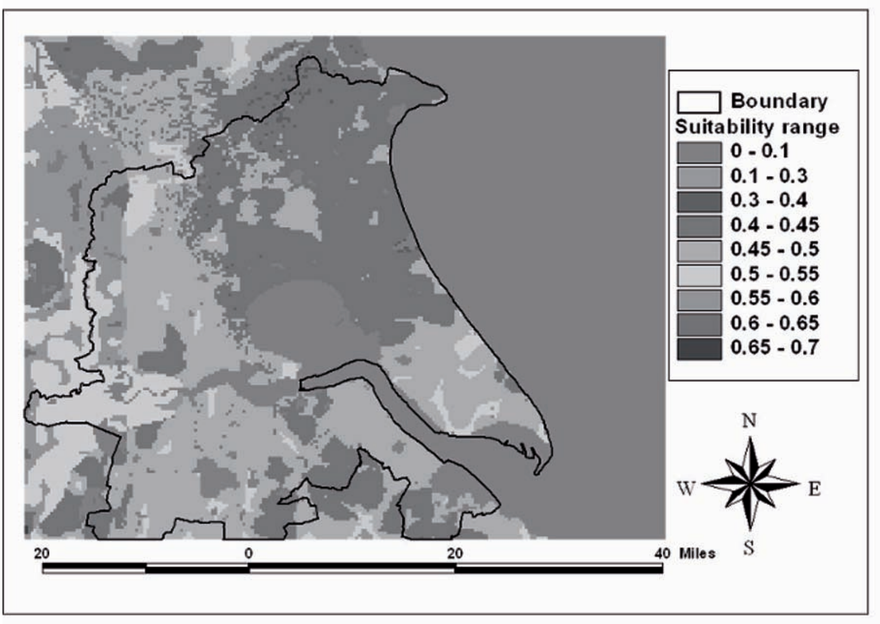

Figure 3 Sustainability map for scenario B

5.1.3. *Scenario C: Equal importance of the sustainability criteria*

The last scenario presented here is based on the principle of equality between the factors that define sustainable development. As was the case in the previous scenario, all criteria participate in the multi-criteria analysis. The aggregated suitability of the sub-region is represented in Figure 4. Examination of the results reveals a disadvantage of this method. Most grid cells receive average suitability values, even those that are of primary importance as is for example steep slope. Evaluating suitability with regards to individual criteria can offset this drawback. Indeed, such analysis is essential to obtaining an overall impression of the study area's characteristics and their influence on suitability. This averaging which is a result of equally weighted criteria, is further illustrated by the smooth appearance of the suitability zones and the lack of high values. The aggregated outcome is almost uniformly average and as such carries less information to support the decision making process.

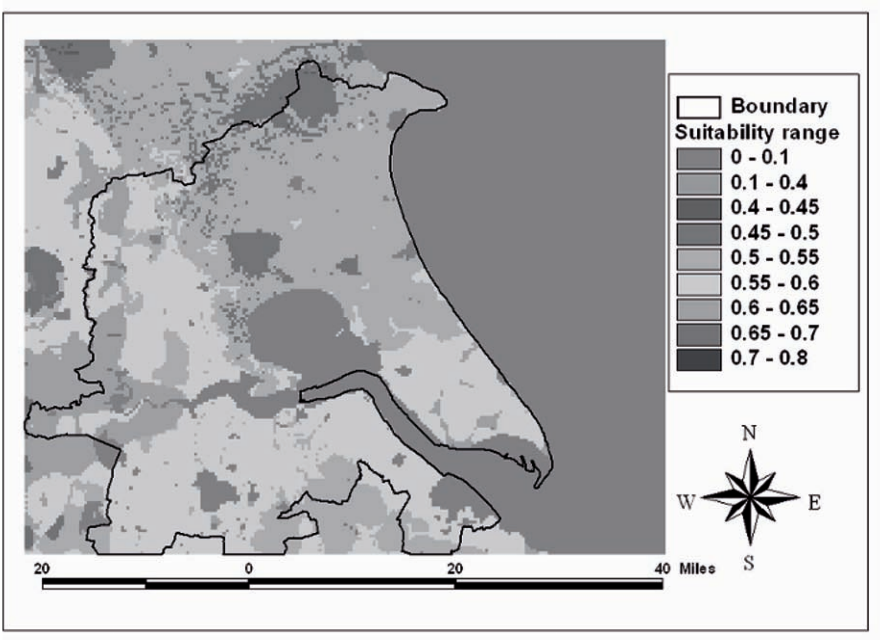

Figure 4 Sustainability map for scenario C

5.2. SENSITIVITY ANALYSIS

The DSS tool offers great flexibility in performing sensitivity analysis. There exist an infinite number of approaches to choosing the criteria, their influence and the means of determining that influence. Sensitivity analysis was undertaken in order to determine the effect of different ranking schemes on the analysis results. The analysis was performed on three scenarios, D1, D2 and D3, each of which represented a different ranking scheme, as shown in Table 5. The objective was to detect the changes caused by the displacement of criteria rank values. The results are displayed graphically to show (Fig 5) the percentage of grid cells with values exceeding specified suitability thresholds. The similarity of D1 and D2 scenario outcomes becomes immediately apparent. The slight differences can be attributed to the effect of individual criteria, but overall the analysis does not seem to be influenced by minor changes in ranking. Scheme D3 introduces switching between the least important and most important rank, while keeping the rest at approximately the same level. The results are spatially similar but an increase in overall suitability becomes apparent. The cause of such a variation in results can be traced back to the effect of certain criteria and consequently to the effects of the FIS rules.

TABLE 5 Scenarios with different ranking schemes

Scenario ID	1	2	3	4	5	6	7	8	9	10	11	12
D1	4	5	10	11	1	2	3	8	9	6	7	12
D2	3	6	9	12	2	1	4	7	10	5	8	11
D3	2	7	8	1	3	12	5	9	11	4	6	10

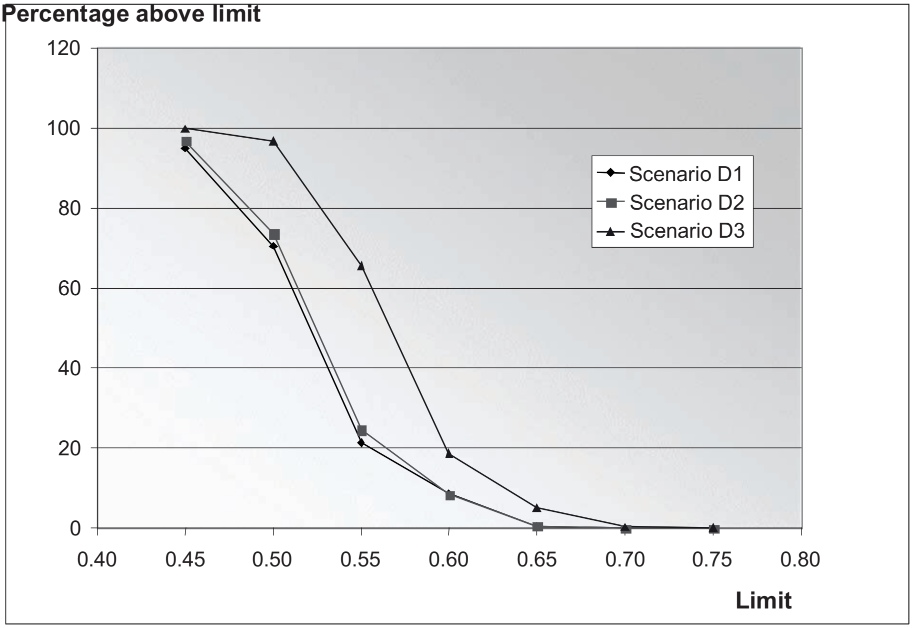

Figure 5 Sensitivity graph for Sensitivity graph for scenarios D1, D2 and D3

The results of the sensitivity analysis suggest that the suitability evaluation using the same criteria is influenced by the order of importance assigned them by the user. It should be noted, however, that other factors in the analysis may strongly influence the final result, but their effect was not examined in this paper. These include but are not limited to: FIS types and rules, defuzzification methods, membership functions and aggregation methods (see for example Makropoulos and Butler, 2004).

6. Conclusions

The work presented here aimed at providing support to site selection for sustainable new urban developments. The paper presented an example of eliciting sustainability criteria for use within decision support systems from basic principles existing within regulation and planning policies and demonstrated the development and testing of a decision support tool operationalising these criteria. The tool incorporates ArcView GIS, an analysis module developed in MATLAB and a user interface created as an Excel spreadsheet. Spatial information is generated from raw data in the GIS and analysed through a set of IF-THEN FIS rules using linguistic variables. The decision maker can affect the procedure by prioritising the various criteria of sustainable development. The issue of site suitability assessment and prioritisation was addressed within a multi-criteria spatial decision framework while the output is presented in the form of GIS site suitability maps.

The tool's application to the Humber sub-region led to a series of conclusions. First of all, the choice of criteria greatly affects the final outcome. The less criteria taken into account, the higher is the resulting overall suitability rating. In the case of the Humber sub-region, the possibility of environmental impacts greatly reduced the overall feasibility, even though the study area was socio-economically advantageous. Clearly the criteria supported by the tool do not represent the entirety of issues related to sustainable urban development, but the tool is flexible enough to include them if the end-user decides to.

In conclusion the decision support tool:

- incorporates existing regulation in the form of sustainability criteria,
- links GIS with multi-criteria analysis modules,
- models uncertainty through the use of fuzzy inference systems,
- enables the construction and application of different scenarios and
- produces user-friendly, easy to understand site suitability maps with degrees of feasibility clearly outlined.

Finally, it is suggested that the tool presented here, although currently at a prototype stage, together with other tools developed within the WaND initiative (Makropoulos *et al.*, 2005) can assist planners and developers to take into account elements of the (water-related) sustainability debate and implement them into strategic planning and development practice.

Acknowledgments

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GIS FOR INTEGRATED WATER RESOURCES MANAGEMENT

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Abstract. GIS and modeling clearly have the potential to make an important contribution to integrated water resources management: indeed, in view of the general scarcity of environmental and health data, some form of modeling is likely to be a prerequisite. Even in the absence of a full understanding of the processes and relationships involved, or of adequate data, the construction of flow diagrams and mind maps can help to develop an appreciation of the issues and help to build consensus amongst the various stakeholders. This paper examines some of the issues involved in using GIS as part of the integrated water resources management process, and illustrates their use with examples from Ukraine.

Keywords: GIS; models; mapping; visualization; spatial interpolation

1. Introduction

GIS – Geo Information Systems may be defined as systems for the manipulation and presentation of georeferenced (i.e. spatial) data. As such, they are able to perform a range of functions, including data capture, data cleaning, data integration, data storage, data search and retrieval, spatial analysis, statistical analysis and data display.

Together with modeling (Nelleman et al., 2003) and GIS (Dalbokova et al., 1999 and Sieker, 2000) are valuable tools in Integrated Water Resource Management (IWRM) development and implementation. They provide a means of:

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- bringing together the information needed as part of the IWRM process in a consistent form; visualising the information in the form of maps;
- deriving statistical and other information from the data; interpreting spatial pattern of water and health; combining information on water conditions and population for health risk assessment;
- monitoring change in water and health conditions, as a basis for evaluating the effectiveness of IWRM.

This paper examines some of the issues involved in using GIS as part of the IWRM process, and illustrates their use with examples from Ukraine.

Our GIS was initiated as a part of the Ukrainian programme on Sustainable Environmental Development and has provided one of the first opportunities to apply GIS at national level. The GIS is built upon a number of basic geographic and statistical datasets. Although it is not yet complete, the GIS is already being used. The examples presented here illustrate some of their applications, but also show some of the dangers and problems in using GIS.

2. GIS Functionality

2.1. MAPPING AND VISUALISATION

One of the most important potential contributions of GIS in relation to IWRM is clearly as a means of display and visualisation. The importance of maps in this respect should not be underestimated: they are extremely persuasive and informative tools. They provide a means of bringing together a large volume of data and synthesising it within a relatively simple and often readily accessible form. They can add value to the data by helping to show spatial patterns and relationships. In some cases, they may also contribute to tests of such relationships, by providing a first-step opportunity to examine possible spatial correlations.

Good maps also carry a clear and often powerful message, which is interpretable by non-specialists, and they help to place this message in context by allowing comparisons between different areas and across space. They are consequently vital tools for risk communication.

GIS help in the production of such maps not only by automating many of the processes, but also by giving the user considerable command over the design and layout of maps. Examples of the use of maps are legion. They include both international atlases and the many national atlases. In recent years, GIS have been increasingly used in this process, both as platforms for data compilation and as mapping tools.

The use of maps to inform discussion of and debate on IWRM nevertheless needs to be viewed with caution. The very power of maps means that they must be carefully designed. The choice of class interval, symbolisation, colour scheme, map projection and scale all have enormous impact on the message, which the map conveys. Unfortunately for the map-maker also, many of the water conditions of interest are not distributed in equal or convenient-sized areas. Typically, for example, statistical data are available for administrative areas, which vary greatly in size, with large, sparsely populated rural areas interspersed with much smaller, densely populated urban areas.

To some extent, GIS help to resolve this dilemma. GIS are relatively scale-free (at least within the limits set by the source data). It is therefore possible easily to zoom in on hotspots, to examine the patterns in more detail, or to zoom out and set them into a wider context. GIS also provide the capability to restructure the spatial information into visually more appropriate forms (Fig.1).

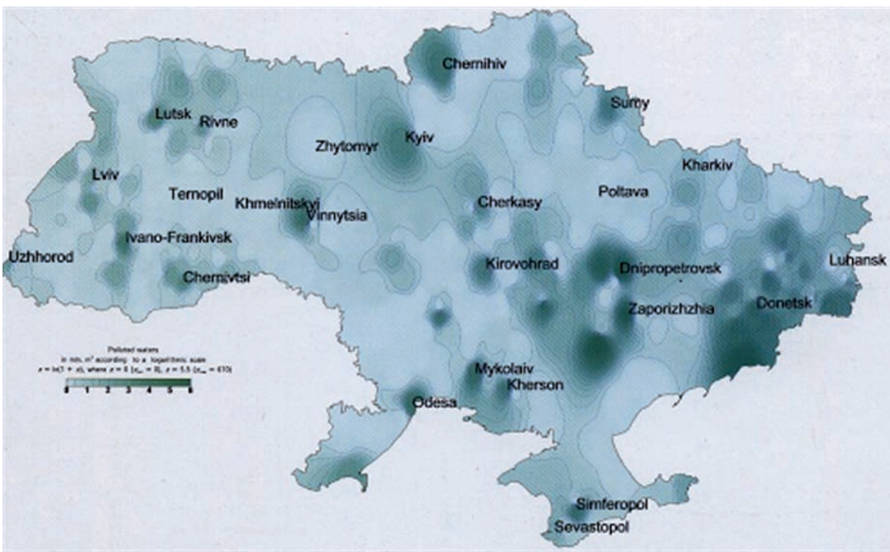

Figure 1 Water quality in Ukraine

One such transformation is the construction of cartograms. These are maps structured not in simple Cartesian space, but within some other conceptual framework. Cartograms may be based on population size, for example, so that the spatial units are reconfigured to represent areas of equal population density. The advantage of this approach is clearly that it helps to highlight areas where the impacts on health are likely to be quantitatively greatest. Their major disadvantage, of course, is that they do not display the information in terms of familiar geographic structures, arid therefore they may be difficult to interpret and may not be readily interpretable by the user.

Differences in the spatial units used are not the only discrepancy, which may affect the data used in GIS, especially when they cross national boundaries. Other - often less obvious - discrepancies may occur in the way in which the data have been defined, collected and reported. Although some organisations have issued standard rules and procedures for coding and classifying, the diagnosis and reporting may still vary substantially from one country (or even one region) to another. Major differences may likewise occur in the way in water data are collected: e.g., in the monitoring methods, survey design, laboratory techniques and classification systems used. Such discrepancies are often not evident within the data themselves (or in the supporting documentation), and may only become apparent when the data are mapped and examined in detail. This emphasises the need to examine all data critically, before the results are accepted as valid, and where possible to validate the results against independent data. It also highlights the need for explicit and agreed data standards for spatial data, supported by clear documentation of data genealogy.

A further problem of interpreting maps is the need to allow for uncertainty in the map estimates. Problems of uncertainty affect any mapped phenomenon: they derive amongst other things from errors in measurement and modelling, inadequacies in sampling, and the effects of classification, generalisation and aggregation. Maps are therefore not precise or accurate representations of reality.

Various approaches have been developed to counteract these effects. One of the most effective is the use of Bayesian map-smoothing techniques, which adjust local rate estimates on the basis of the denominator.

2.2. SPATIAL INTERPOLATION

Maps are, by their very nature, constrained by the data on which they are based. In the case of environmental maps, especially, these data are often incomplete. Much water data is based on sampling at a limited number of monitoring or survey points: water quality data, for example, are typically available only for a limited number of monitoring stations. In order to quantify the health risk, which these conditions imply, the data need to be extrapolated to represent the population as a whole. One way of doing this is through the use of spatial interpolation. This is the process by which estimates are made of conditions at unsampled locations, based upon data from measured points. These estimates can then be used to provide the basis for constructing a map giving a complete and continuous coverage of the area of concern.

A range of spatial interpolation techniques are available in GIS. The main differences are between global methods (e.g., trend surface analysis), which fit a single mathematical surface through all the data points, and local methods (e.g., kriging, thin plate splines) which fit locally adjusted surfaces. The performance of the different interpolation methods depends upon a number of factors including the nature of the underlying spatial variation in the phenomenon under consideration and the sample density and distribution. In general, however, there are reasons to favour local methods of interpolation over global methods because the former are more sensitive to local variations in the data and thus do not produce as much smoothing of the modelled surface. Kriging and thin-plate spline techniques also provide error estimates for the modelled surface.

Spatial interpolation methods are widely used in small-area studies, where they can provide a powerful means for analysing. Their use at national level (the scale more appropriate for IWRM) is more limited, largely because of limitations of suitable input data. Although national monitoring networks can provide useful point data (e.g., on air quality), the distribution of these sites is often inadequate as a basis for national mapping. Most pollution monitoring sites, for example, tend to be in urban areas; interpolation based on these is likely seriously to overestimate pollution levels in the intervening rural areas. Indeed, this is a problem even at a local level.

One way of improving on this process is to make use of additional, exogenous information (covariates) to assist the interpolation process. Covariates are variables, which are correlated with the pollutant of interest, but are measured at a higher density of sites than the pollutant itself. Thus, data on emissions or traffic flows might be used to help predict levels of pollution between sample sites. One method for doing this is co-kriging. An alternative approach is regression mapping. In this case, empirical relationships can be established between environmental factors and the pollutant of interest, based on a set of data. The resultant regression model can then be used to predict pollution levels at unsampled locations. This approach was successfully used to map traffic-related water pollution. Validation of the map was carried out by comparing predicted concentrations with monitored levels at a set of reference sites (i.e., sites not used in the initial regression analysis).

2.3. MAP OVERLAY AND INTERSECTION

Potentially one of the most important characteristics of GIS in relation to IWRM is their ability to overlay and intersect different maps. This offers a number of important capabilities. For example:

- maps of pollution and population can be overlayed in order to identify and quantify the population at risk, or to estimate potential exposures;
- maps of different hazards may be overlayed and combined in order to generate a composite index of health risk;
- maps of hazards and health outcome may be compared in order to investigate potential associations

None of these applications of GIS is trouble-free; all need to be undertaken with care. In particular, close attention needs to be given in all these cases to the potential errors in the data: by combining different maps, complex error surfaces may be generated, which are not always apparent to the user. In this context, it is important to remember that maps of water conditions are, at best, only estimates, and are subject to considerable errors and uncertainties. The maps themselves may also be dependent upon the distribution of the source data points, and the models of interpolation used. Scale and resolution are also vital considerations. Because GIS are essentially scale free, it is relatively easy to combine maps of different scale, and thus of different spatial resolution. For example, generalised maps of pollution may be intersected with detailed maps of population distribution, to estimate exposures at the place of residence; or high-resolution maps of land use may be combined with broadscale maps of geology to estimate the potential for leaching of agricultural wastes into groundwaters. In any such application, however, the apparent detail in the resulting maps is likely to be false: the accuracy of the results will be limited by the accuracy of the poorest data set used.

One of the main difficulties in comparing and overlaying maps, however, is that they are often based upon different spatial structures. Whilst most water and socio-economic data, for example, are attached to administrative units (though not necessarily the same ones), many environmental data are attached to points, lines or 'natural' areas. In order to compare or combine different data sets, as part of IWRM, it is therefore commonly necessary to convert the data to a common spatial structure. This can be done within a GIS by redistributing the environmental data to smaller spatial units (e.g., a fine grid), then reaggregating to the required administrative areas.

How effective this process is depends to a great extent upon the validity of the underlying spatial model. At its simplest, spatial transformation is a process of area-weighting: data are disaggregated solely according to the proportion of the area contained within each sub-unit. This, however, may not always be appropriate, and exogenous data may be used to apply other weighting models.

Perhaps one of the most important sources of information in this context is land cover data (e.g., derived from remote sensing), for this can act as a powerful indicator of the true distribution. Thus, data on land cover may be used to apportion population data from aggregated units (e.g., counties) to smaller areas (e.g., communes), in order to provide best estimates of small-area population numbers. Similarly, land cover data may be used to apportion aggregated data on emissions to local areas, in order to provide small-area exposure estimates. (Fig.2 and Fig.3).

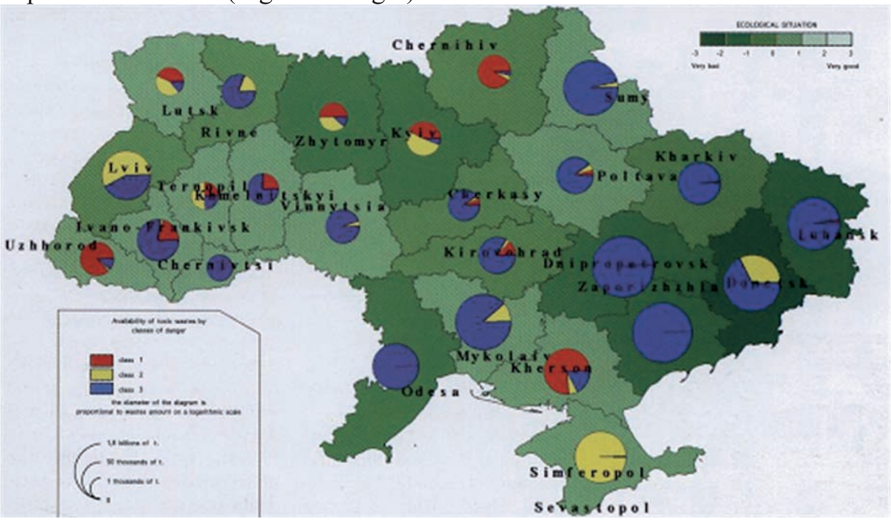

Figure 2 Soil quality in Ukraine

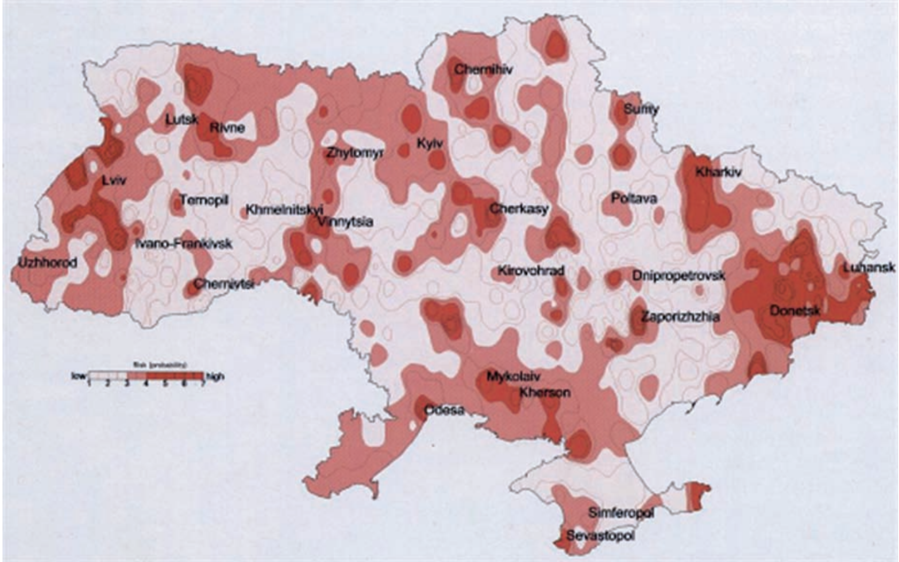

Figure 3 Population at potential risk to access to clean water in Ukraine

3. Conclusions

GIS and modeling have the capability to play an important part in the IWRM process. Nevertheless, the use of GIS carries with it significant dangers, for GIS are influential and persuasive instruments. It is consequently all too easy to use them to promote false interpretations or promote inappropriate perceptions especially through the naive or simplistic use of maps and mapping techniques.

Many of the dangers inherent in using GIS in support of IWRM stem from the scale of analysis implied. By their nature, IWRM demand information on water and health at the national level. Much of the knowledge about water health relationships, and much of the information on water conditions is, however, extremely local. It derives from small-area or individual scale studies under controlled conditions. The challenge is thus to generalise from these local scales to the national level. GIS certainly provide the technology to do so, with relative ease, for as mentioned they are largely scale-free. The validity of such generalisation is, however, often open to question.

So long as these issues are kept in mind and they are used with caution, however, GIS have much to offer. They help to collect and integrate spatial data on water and health within a consistent form. They provide a means for visualising and displaying these data as maps. They are powerful tools for spatial interpolation and modelling. They enable environmental and population data to be overlayed and compared in order to quantify the population at-risk. They can help to analyse relationships between health end exposure. In all these ways, they can make valuable contributions to IWRM, both by helping to identify and quantify health risks, and by communicating these to decision-makers and other stakeholders.

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URBAN INFRASTRUCTURE MODELLING

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Abstract. The practical application of a simulation modelling for large size urban drainage systems is subjected to a number of simplifying assumptions, constrains and bottlenecks which require a high level of user abstraction and interpretation on a side of project team and the client. A good technical formulation of project tasks as well as a proper schematisation of a system structure and process is the essential milestone for a successful completion of the project. In the same moment numerical modelling of water supply and water distribution systems has become a standard and an inevitable practice in any serious attempt of evaluating hydraulic, water quality, and economic aspects of these complex systems. Modelling capacity of well-suited models, featuring advanced technologies including linking the models to GIS systems and telemetry systems, accurate fire flow calculations, water quality analysis, and leakage reduction is incomparable with any alternative approach for these purposes. Hydraulic modelling of water supply and water distribution network is used for planning linking-up consumers to the network and evaluating the remaining capacity of the network, modelling of network's breakdown, modelling of various loading and operational states of the system including fire flow analysis, reconstruction of existing and planning of new pipes, pressure zone optimisation, leakage reduction and others.

Keywords: integration of models; mathematical modeling; urban drainage; water supply system.

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1. Introduction

In previous years projects and approaches in urban drainage and water supply systems were separated from the execution point of view. But in reality, processes described in these projects are just parts of particular water cycle in urban areas. Both of them are essential tools for assessment, maintenance, designs or farther development of whole systems. Therefore some similar approaches as well as differences will be presented for both topics, considering similar or even common projects executed. The main principle of the contemporary methodology is the complexity, the effort to see each problem as a piece of a more complex puzzle in relation to the other problems, not to see the particular problem as a separate one, which was many times done in the past. Furthermore, we may take advantage of still more and more accurate computation capabilities provided mainly by the computers in general.

The practical experience with modelling packages as well as a work with a number of pre-processing and post-processing tools proved and highlighted the necessity of a large portion of "know-how" knowledge to be available within the urban infrastructure project team. This paper is devoted to the experience with an application of hydroinformatic tools for a both, urban drainage and water supply conceptual projects.

2. Water Supply

Mathematical modelling of water supply and water distribution systems has become a standard and an inevitable practice in any serious attempt of evaluating hydraulic, water quality, and economic aspects of complex systems. The scope of problems where the modelling is used as a basic tool has been continually enlarged. Numerical modelling of water supply and water distribution network is used in scope of

1. **Master plan of the water supply system**
   - Conceptual model of the whole system covering the existing and future scenarios. Used for the long-term planning and strategic decisions
   - Helps system planning and development. Suitable for strategic decisions.
2. **Zone Rehabilitation**
   - Suggest the optimum network design, size pipes, and fire hydrants
   - Optimum system design
3. **Pressure Zone Optimisation**

- Optimise the system by reducing the pressure according the water supply standards
- Decrease the leakage and reduce the pumping and operational costs

4. **Leakage Modelling**

- Analyse, measure and model leakage in the system
- Decrease leakage

5. **Fire Flow Protection**

- Fire flow analysis, fire flow protection and fire hydrant capacity
- Fire flow protection

6. **Water Hammer Analysis**

- Water hammer protection of the pumping stations. Air chambers sizing.
- Minimise the risk of the transient flow damages.

7. **Water Quality Analysis**

- Water age, course tracing, and residual chlorine concentration
- Improve the water quality parameters

8. **Water Quality Risk Analysis**

- Dangerous bacteria or other substances entering the network
- Increase the preparedness of the water utility to react on unexpected events
- Minimise the risk

9. **OnLine Modelling**

- Implementation of ON-LINE models into the SCADA system. Real-time modelling of the hydraulic, water quality, and economical parameters.
- Decrease the operational costs of the system
- Suitable for the operators training, IF-THEN scenarios

Building up of the mathematical models is a quite time and financial demanding work. The universality of well-suited models for solving of wide range of tasks has become an actual problem of many utilities to increase efficiency of the invested effort. Integration of the mathematical models into the structure of existing utility information system enlarges the models validity as well as the information content of the IS. The incorporation of the mathematical modelling into the IS structure is supported by the open architecture of the IS components, which has become a common characteristic of the up-to-date software solutions. There is a lot of tools on the mathematical model’s side supporting their incorporation into the utility IS such as:

- Open data connectivity as ODBC, AOL…
- GIS formats import, export, update tools
- Incorporation of CIS data sources based on tools as Demand Allocation
- Model and Boundary Management
- On-line application
- …

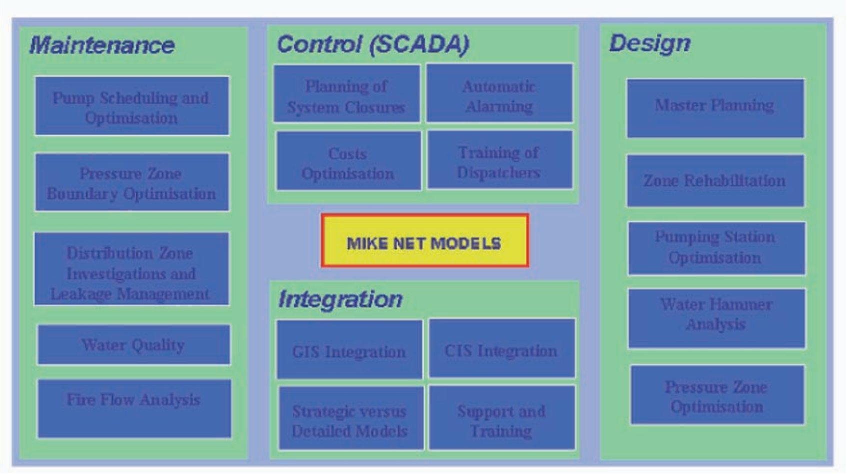

Figure 1 Overview of the scope of the mathematical model's utilization

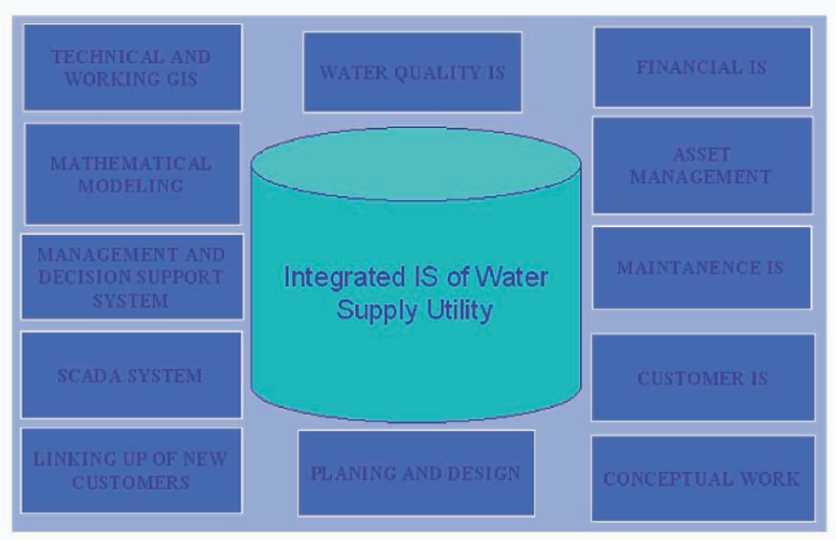

Figure 2 Components of Integrated IS of a Water Supply Utility

The definition of the mathematical modelling integration into the Water Supply Utility structure is an ambitious assignment up to certain extent individual for the actual conditions of the Utility. Definition of the extent of the integration as well as the study of possible enlargement of the role of the mathematical modeling must be done based on the combination of Utility conditions acquaintance with the experience of the model utilization in the many other Utilities.

The necessary steps of Integration project are:

- Definition of the scope of model's utilization
- Decision about the role of Strategic and Detailed models
- Management of the models
- Evaluation of existing model's capability for the tasks
- Increasing of the model's universality
- Unification of the models
- Covering of all the appropriate water supply elements by models
- Definition of the links into other IS components

- Inputs into models (GIS, CIS, SCADA, field measurements and inspections, proved limits of the customer's water demand, investment planes…)

- Outputs (GIS, SCADA, System operation, Investment plans, Maintenance plans, Decision Support System…)

- Definition of the Implementation phases and their outputs

3. Urban Drainage

There is a high number of multi-branch activities in the field of urban drainage. Main group of projects is listed below.

3.1. ASSET MANAGEMENT DATA PROCESSING

Nowadays a lot of system and software tools handling and managing the sewer network data exist. One of main task starts to be a data communication among these products. There is a wide range of experiences in data communication because of various inputs for modelling requires to process the data from different data sources.

Asset management data processing is important step for an efficient management of the water company. The data can be used for several purposes as mathematical model build, operation of the sewer network, GIS application etc. The first task is to analyse data sources and convert relevant data to both digital and printed forms. The second task is to make an assessment of the asset property.

3.2. SEWER NETWORK MASTER PLAN

The sewer network master plan is an essential document used for a long term strategy planning and an investment to the sewer network. The sewer network master plan is based on modern approaches as digital data processing modelling and monitoring. Key points of the project are described bellow. These activities can be understood as activities executed in both ways as in frame of master plan or as individual projects.

- ***Model build up and model calibration.*** Model build represents processing of various data before the model is completed. The advanced techniques are used to be used to reach maximum efficiency and accuracy. The application of the mathematical model in frame of the master plan needs verification of computed data against filed flow measurement. To receive proper results the model has to present good fit to the reality; and model verification is a process which proves if it is so.
- ***Evaluation of the network capacity.*** Elaboration of capacity of the sewer network gives us information how the system behaves. Using the model a critical situation can be modelled and the model can answer engineering question as “What happens in such condition” etc. The results of the evaluation are presented in form of thematic maps, tables and charts. The results are overloading of the system, CSO function etc.
- ***City development influence on sewer network.*** A rapid development of an urbanisation requires detailed and complex understanding of the sewer network behaviour. Especially new zones development in suburbs need detailed evaluation of the network, because the problems can be observed not at the zone but down the network. This evaluation can be done using the model of the sewer network extended to new areas. The analyses of the simulation indicate critical points of the system and appropriate solution can be found.

3.3. URBAN DRAINAGE MASTER PLAN

The urban drainage master plan focuses on not only sewer network, but for urban creeks as well. The urban drainage master plan deals with a concept of the city development in terms of sewer network with respect of detailed evaluation on receiving bodies impact. The urban drainage master plan is a multidisciplinary project which includes a lot of expertise work e.g. mathematical modelling, monitoring, biological evaluation of creek, economical analyses etc.

- ***Infiltration/exfiltration assessment.*** Infiltration and Exfiltration assessment can be used for identification of potential sources of infiltration. Several methodologies are used based on information available/accessible. The assessment shall be combined with a monitoring campaign. The results of the assessment are risk zones for infiltration and estimated amount of the infiltration within them.
- ***Sediment and pollution Transport.*** Sediment and pollution transport can be modelled as one of phenomena occurred in sewer network. The results of the model are zones where sediment is deposit and zones where the sediment is eroded. The transport process can be animated as well. The flow condition when sediment transport starts are analysed from the simulation too. The pollution connected with sediment can be modelled a well, the result of such simulation answers questions regarding actual concentration of the pollution in defined point or quantify an amount of the pollution transported over a CSO to a recipient.
- ***Water balance.*** The balance of water is key point in understanding of the system behaviour. The balance shall be done for whole catchment itself as well as for individual structures inside the catchment as are subcatchments, pumping station, CSOs, WWTP etc.
- ***Interaction Sewer - WWTP – Recipient.*** The interaction between Sewer network - WWTP - Recipient is a technology based on integrated understanding of a catchment behaviour. The process of integration requires completed models of all three elements; models are interconnected in key points. A benefit of the integrated approach is modelling of the interaction in “real” time, which can bring an extra information in detailed study of processes in water management.

3.4. SEWER NETWORK PERFORMANCE DURING RIVER FLOOD

River flooding are quite often phenomena nowadays, food protection barriers are build in many cities. Flood protection project has one goal: to protect the city from water from the river. The question is, what will happen if it starts rain in the city and at the same moment there is a flood in the river. The sewer network is not designed for such condition, because of outlets from CSOs are blocked by river flood protection. Then a risk of flood the city by water from sewer network rise. The project of Sewer network performance during river flood condition simulates such situation. Based on its results a flood protection system can be improved to be capable minimise negative impact.

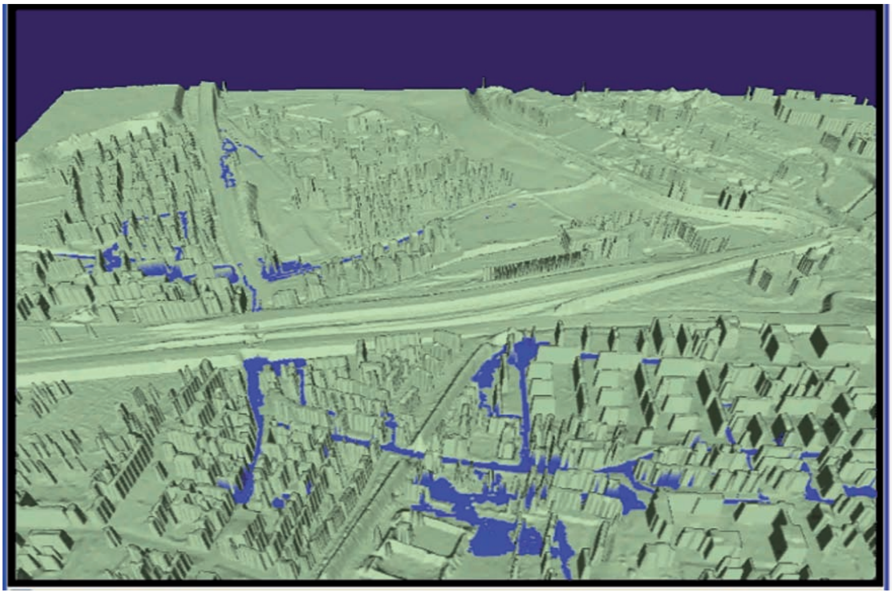

Figure 3 Urban flooding – visualisation of results (MIKE Animator)

4. Conclusions

There are a number of multi- criterial and multi - branch activities in both, urban drainage and water supply system. A current trend/vision is not only an integration of project task under an umbrella of conceptual projects (Master Plans), but next steps in the field of urban infrastructure are targeted to the integration of both, urban drainage and water supply systems to the overall concept of urban infrastructure modelling. A few of such concepts are nowadays available, such as MIKE URBAN from the DHI Software family. However, the attention should be focused not only on tools, but preferably on task and project formulation and results elaboration.

INTEGRATED URBAN WATER CYCLE MODELING

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Abstract. New trends are increasingly recognized in the software development business. These trends are following a couple of fundamental terms „integration“ and „openness“ and originate from long term users needs for software tools with integrated functionality and open human interface. The paper is focussing on current experience with software products and basic requirements originating from practical software use. Then a basic concept of “integrated and open” software architecture is introduced and documented on new product MIKE URBAN for integrated modelling of urban water cycle. It is argued in the paper that “integrated and open” architecture meets most of current user needs while bringing to users higher effectiveness and comfort of work.

Keywords: data; geo-database; GIS; GUI; integration; mathematical modeling; OMI; urban drainage; water supply.

1. Introduction

There are new trends recognised in the development of information technology and particularly in software development. These trends are focussing on technology integration, increasing openness in interfacing, flexible human interface configuration and intuitive working environment. The main purpose of this approach is seen in the integration of distinct functionalities and consequently in increase of comfort and flexibility of use. The civil engineering sector has been utilising information technology already for number of years to

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improve operation, management and planning processes. It is then obvious that the phenomenon of integration and openness is touching also this area as it is clearly documented on technology of simulation modelling (see Marsalek et al., 1996).

Distinct simulation models are being coupled to exchange the data or even to run in parallel on the same calculation time step. Simulation models are getting coupled with GIS functionalities (including the new concept of „geo-databases“), SCADA, CAD or asset management systems and they are gaining the features of robust information systems. These new trends in software development represent a response of software producers to long term user needs originating from daily experience with modelling techniques for practical project tasks.

2. Experience with Standard Simulation Models

The work with standard simulation model represents a complex process subjective to the deep knowledge and understanding of model potential, advantages and bottlenecks (see Metelka et al, 2001). Moreover, practical use of simulation modelling demands from users also high level of other software knowledge (e.g. databases, speedsheets, CAD, GIS, etc.), good understanding of data formats and their conversions and sometimes even experience in programming techniques. Moreover, large volumes of data necessitate systematic and careful approach while building up the model for particular project purposes.

All above requirements demands from civil engineer high qualification and bring about the process of model built to be tedious, timely and in consequence also expensive activity increasing the project cost though it brings higher quality of results in comparison with classical engineering approaches. Some of the problematic aspects of using the simulation models are described in next paragraphs.

The transfer of data between distinct programs represents at present very obvious task during the model built phase. The work allocated for these activities represents a substantial part of overall project work (between 40-60%). At the same time these activities are subjected to probability of implementing random or systematic errors which are difficult to recognise.

The development of overall project documentation represents another crucial task during the project execution. Current high demands on the form of produced maps, graphs and tables enters the area of GIS or CAD tools and logically exceed possibilities of many of present simulation tools.

The model integration between distinct simulation tools (e.g. coupling of sewer and river model) is a problematic issue to cope with (see Metelka, Pryl,

1999) and represents a substantial amount of manual work. There is a legitimate requirement to improve mutual communication of distinct modelling engines.

The simulation model represents a digital copy of real physical systems (e.g. sewer or water supply systems). It seems to be logical, that once built simulation model can be used for a long period of time for the system analyses aiming in performance optimisation, reconstruction planning or even real time control or early warning. The long term continual model utilisation is based on the continuity in data management (see Krejci, 2000) and is closely related to quality of respective data model, defined form of data storage and upgrade as well as free access to model database data. The role of well documented data model and flexible data structures is then essential for long term model use.

The parallel modelling and design activities constitute one of key factors in terms of effectiveness - mainly for large detailed planning simulation models. Moreover, shared data represent important communication platform having the same semantics for many actors. There is a clear need for common access to these data for planners, modellers as well as stakeholders.

Next basic requirements on modern simulation model can be derived from above facts.

- Simulation model should integrate standard CAD and GIS functionalities including advanced layout.
- Model data should be stored in geo-database including graphical features so, that the data would be independent from used technology and easily presented at any GIS system.
- Simulation model should offer suite of distinct simulation engines to give the user chance in selecting preferable model engine for particular civil engineering task.
- Simulation model should minimise a number of data transfers and propose easily accessible and handled data structure.
- Simulation model should support a multi-user, multi purpose data utilisation.
- The long term development and maintenance of simulation model should be supported by software providers.

The user requirements originating from day to day work with simulation tools clearly indicate common need for new technological step in software development of simulation tools (see Metelka et al, 2004).

3. New Software Approaches and Standards for Integrated Modelling

Meeting user demands requires from producers of simulation models search for new approaches and standards to be used in software development. The „openness" and "integration" features are then key elements of new system design and they are getting applied at distinct levels of system architecture. In following, basic system design approaches and standards are described.

- Coupling with GIS systems

Coupling with GIS system represents a common strategic feature for most of present simulation models. However, this coupling is many times mixed up with development of an "extensions" on top of GIS, which does not represent real coupling of technologies.

- COM component based architecture

To be open and easily integrated the software has to be component based. Present software development is successfully using concept of COM (Component Object Model) and its alternatives to share distinct pieces of code in a form of components with specific interfaces. These components can be then used independently of the source code in distinct software packages.

- Open database access

Open database access belongs to key features representing system openness. Current RDBM databases are in principle accessible via ODBC or OLE DB connections. The most appreciated connection is however a native database structure readable without any support.

- Open and integrated data structures

The concept of "geo-database" is applied in modern simulation tools. This means that not only attribute data but also topological features are stored in one compact database. This fact simplifies the data portability and overall data management. In addition, well documented data model should be a part of modern simulation tools. UML relationship modelling can be used to represent data structures.

- Model coupling

Model coupling can be implemented at several distinct ways. The easiest coupling is based on exchange of data files. This way, most of present simulation models are cooperating. However, there is a new concept invented and gradually getting used called Open Modelling Interface (OMI). By implementing this concept distinct software tools can cooperate on single simulation time step at arbitrary number of selected calculation points. During the calculation all hydraulic phenomena (e.g. back water, retention, wave movement, etc.) propagates throughout the coupled systems.

- System configuration

Configured GUI (Graphical User Interface) is being implemented in many present software packages. The issue however is, which flexibility can be achieved by configuring the system. The advantage can be seen in the possibility of programming on top of simulation model with help of Visual Basic, C++ or other development environments. This way the user can really change and extend the functionality of simulation tool by developing his/her own components for particular handling model data.

4. MIKE URBAN – Integrated Software for Urban Water Modelling

DHI Water & Environment belongs to one of main players in software development for water related management and planning. There was developed new integrated software package MIKE URBAN in DHI recently. MIKE URBAN is a representative of new software generation of „open and integrated“ tools complying with users requirements as well as software approaches and standards defined above.

The MIKE URBAN is technologically integrated with ESRI ArcGIS platform. The component structure of ArcGIS using ESRI ArcObjects establishes very good technological background for MIKE URBAN architecture and guaranties long term continual development of MIKE URBAN in parallel with ESRI products. Coupling of MIKE URBAN with ArcGIS brings a number of new useful GIS functionalities oriented on topological data analysis. There is very comprehensive „networking“ functionality inherited from ArcGIS and implemented in MIKE URBAN. This functionality performs advanced data connectivity and integrity checks on sewer or water networks. The user defined tracking, search for loops or disconnections can be then applied on the network. The „geo-processing“ tool is to be mentioned as other analytical functionality on top of system topology. This functionality can be used for connecting catchments to manholes in sewer model. The use of GIS functionality brings advantages also in polyline shape of pipes, advanced graphical selections, comprehensive reference coordinate system selections, user defined labelling or flagging and of course work with data layers including layers with simulation result data. The layer management functionalities give the user chance to connect his model with arbitrary number of background layers.

MIKE URBAN is using the concept of „geo-database". All model attributes as well as topological data are stored in ACCESS geo-database. This fact shows up to be rather important from the point of view of data consistency, long term data management and multipurpose utilisation. MIKE URBAN data can be used by any of ArcGIS components as „native" data. There is no need any longer for storing graphical features in specialised files (e.g. SHP, DGN, MAP, etc.). MIKE URBAN geo-database can be used by any GIS system supporting this concept.

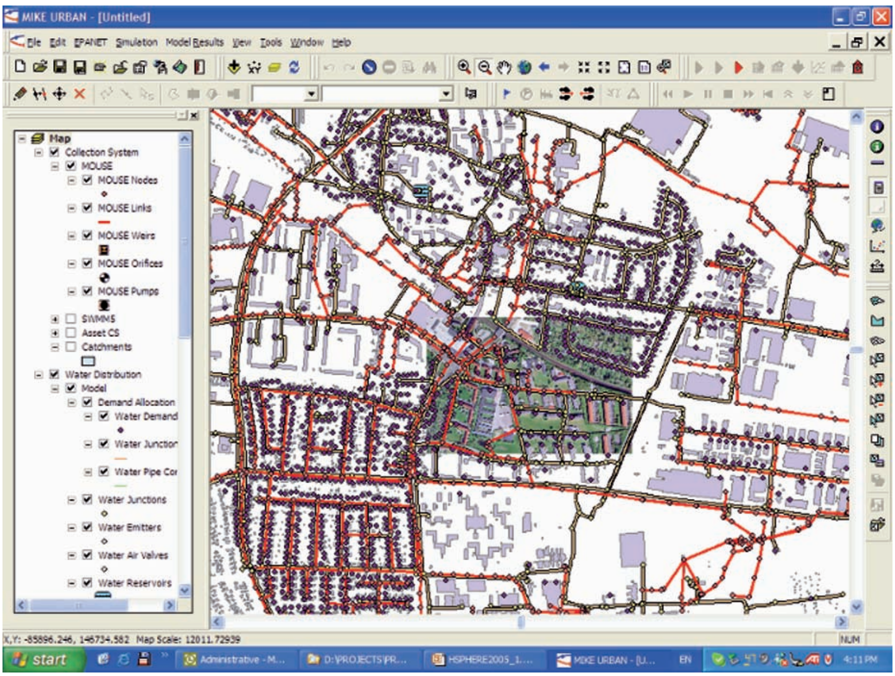

Figure 1 MIKE URBAN result presentation features

MIKE URBAN integrates simulation models for water supply and urban drainage systems. User can work in parallel with both sewer model and water models in the same graphical framework, he can animate the results in parallel and even share some relevant data between models. This way MIKE URBAN becomes very promising software package specially for Water Utility companies. Due to component structure MIKE URBAN also makes the selection of preferred simulation engines possible. At the moment MOUSE, SWMM, EPANET and Water Hammer engines are accessible through the program environment however, it is expected that this will be extended in the near future.

MIKE URBAN data structure consists of 5 data models making the parallel work on three types of model (MOUSE, MIKENET, SWMM) and two type of asset management systems (ASSET-sewer, ASSET-water) possible. The respective data structures are mutually connected so, that the data sharing is made possible between distinct systems. The special interest should be devoted to couple of asset management systems. These systems can be used for storing original system data before the conceptualisation is performed on data during model built procedure. Later user can visualise and compare (or even import back) original data with model schematisation and verify its relevance and complexity.

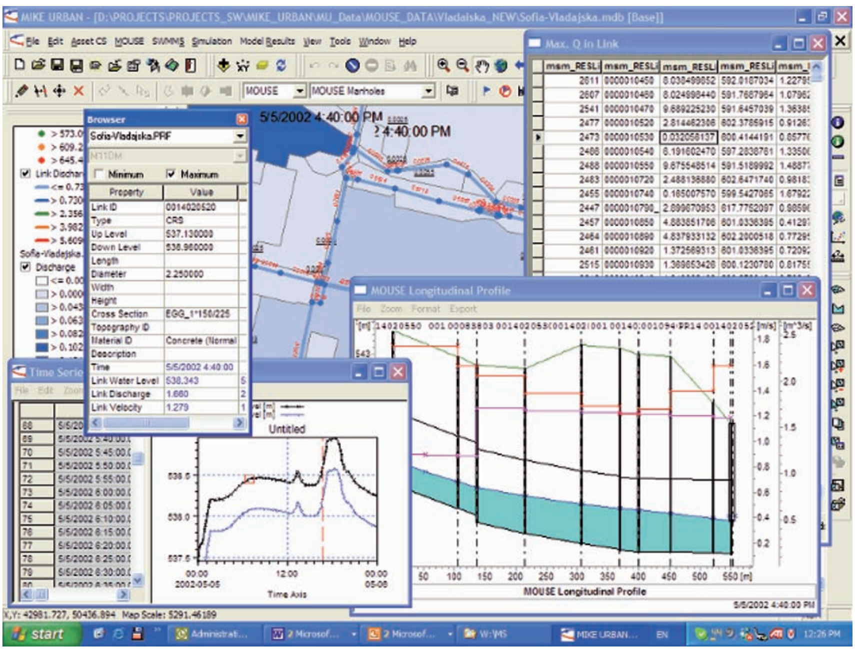

Figure 2 MIKE URBAN result presentation features

MIKE URBAN is fully configurable by means of XML files. These files can be used to configure local program language, user defined units, data imports/exports, etc. Moreover, MIKE URBAN is open for development of advanced user tools as program "extensions" using C++ or Visual Basic programming environments.

5. Conclusion

At present, an integrated water cycle modelling requires complex software support to be able to cope with the complexity of current engineering tasks. The requirements put on the software development can be summarised in terms of "openness and integration". These requirements are gradually getting met by software providers as shown on case of DHI and their MIKE URBAN product. Software products of this new type brings new quality in engineering work with accent for solution transparency, flexibility of usage and long term data utilisation. However, the "up-skilling" and higher user knowledge is demanded from the current specialists in the area of simulation modelling.

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WATER RESOURCES POLICY AND MANAGEMENT IN JORDAN

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Abstract. Jordan water resources are very limited, among the lowest in the world on a per capita basis. Water demand at present exceeds the available renewable water resources which have been overexploited to bridge the gap. This gap is expected to widen in the future in all water sectors. This situation can not be maintained without endangering sustainable development. The adoption of a new strategy for water planning is therefore crucial. The strategy should focus on demand management and development of non-conventional water resources. The objective of this paper is to present the water situation in Jordan along with various components of water development and planning, and future water management scenarios.

Keywords: demand management; desalination; fossil water; Jordan Red-Dead Sea Canal; wastewater reuse; water conservation; water pricing.

1. Introduction

Jordan is about 90,000 km^2 in area, and lies among the dry and semi dry climatic zones which are characterized by their minimal rainfall and high percentage of evaporation. Its climate is a mix of Mediterranean and dry desert climate. The temperature varies from a few degrees below zero in the winter to around 46 degrees centigrade in the summer season. Annual precipitation ranges from 50 mm in the desert to 600 mm in the northwest highlands. Only

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nine percent of Jordan's area receives more than 200 mm of the rainfall annually. Approximately 92.2% of the rainfall evaporates, 5.4% recharges the groundwater and the rest 2.4% goes to the surface water.

Recently, the problem of water shortage in Jordan has been exacerbated as a result of high natural population growth, influxes of refugees and returnees to the country in response to political situation in the Middle East area, rural to urban migration and increased modernization and higher standards of living. Consequently, Jordan is facing a future of very limited water resources among the lowest in the world on a per capita basis. Available water resources per capita are decreasing as a result of population growth, they are projected to decline from more than 160 m^3 per capita per year for all uses at present to only 91 m^3 per capita per year by 2025, putting Jordan in the category of having an absolute water shortage (Al-Halasah, 2003).

2. Available Water Resources and Water Demand

In the year 2000, the amount of water supplied was about 817 million cubic meters (MCM). Out of these 473 MCM came from groundwater, 272 MCM from surface water sources, and 72 MCM from treated wastewater (MWI, 2002a). Municipal uses represented around 29%, irrigation uses represented around 66%, and industrial uses represented around 5% of the total consumption (MWI 2000). Based on projections of available water amounts, the gap between supply and demand from all sources is increasing annually. Despite the huge investment in the water sector for the coming years, water deficit for all uses is projected to be 437 million m^3 by the year 2020, comparing with 320 million m^3 in 2000 (MWI, 2002a). These figures show the necessity for adopting a long term water plan and future scenarios of water management that consider both demand management and non-conventional water resources, in order to decrease the gap between supply and demand.

2.1. SURFACE WATER RESOURCES

About 91% of Jordan's area receives an average annual rainfall below 200 mm. Estimates of long-term records indicate that the average annual rainfall volume over the country is around 8360 MCM (World Bank, 2001). Surface water is developed through 14 surface water basins distributed all over the country. Surface water resources consist of base flow originating from the discharge of groundwater through springs. Floodwater resulting from rainfall in winter is the second category of surface water. The amount of flood water fluctuates from year to year, with an average of about 255 MCM. The long-term average surface flow is estimated at 710 MCM (JICA, 2001). Currently there are 26 dams in Jordan with a storage capacity of 254 MCM to harvest floodwater. Other dams are under construction or planned. Al-Wahda dam (under construction) will provide about 60 MCM for drinking water purposes from flood water in the Yarmouk river (JICA, 2001).

2.2. GROUND WATER RESOURCES

Groundwater basins constituting Jordan are very scarce and vary in quantity and quality. They are constituted from three main aquifer systems distributed vertically according to the geology of the basin. These aquifer systems are namely the upper aquifer system, intermediate aquifer system and deep aquifer system. Groundwater in Jordan is of two types, renewable and nonrenewable fossil water distributed among 12 basins. The safe yield of renewable groundwater basins is around 275 million m^3 . In the year 2000, the abstraction of groundwater resources was 473 million m^3 to meet the required demand; 411 million m^3 was from renewable groundwater (150% of the safe yield) and 62 million m^3 from fossil water (Al-Halasah, 2003). Continuation of groundwater overexploitation at these high levels will lead to mining these sources as well as deteriorating the quality of abstracted water, which will lead at the end to an extensive damage of the aquifers. The most important non-renewable groundwater resources are the Disi and Shedia fossil aquifers in southeastern Jordan. Currently the Disi aquifer is used to supply the city of Aqaba with water for domestic purposes, and is being used for agricultural purposes in the Disi area (Jaber and Mohsen, 2001). The utilizable fossil ground water is estimated at 90 MCM per year for a period of 100 years (Mohsen and Al-Jayyousi, 1999).

2.3. NON-CONVENTIONAL WATER RESOURCES

Different non-conventional water resources are considered as potential water resources. These include treated wastewater, water harvesting, and desalination of brackish and sea water, in addition to proposed mega-scale projects. Following are brief descriptions of these resources:

2.3.1. *Treated wastewater*

Jordan has relied for the past two decades on waste stabilization ponds to treat wastewater for reuse in agriculture. These plants have been or are being replaced by mechanical treatment plants, namely conventional activated sludge and extended aeration plants. In existing and planned extended aeration plants, nitrification/denitrification and in some cases phosphorous removal is practiced. Sand filtration and/or maturation ponds are also being used. Effluent quality of some of the newly operated plants is very high, which made it possible to explore new reuse applications in Jordan such as industrial cooling, groundwater recharge, and even municipal use (Ammary, 2005).

Current and planned wastewater treatment plants will have an estimated combined treatment effluent usage of 245 MCM in the year 2020, which will assist in providing water for irrigation. In the year 2000, 72 MCM of the treated wastewater were used for irrigation (MWI, 2002a). For sustainable reuse of wastewater, some steps have to be taken. Industrial discharges in the future may increase and therefore have to be carefully monitored. High salinity wastewaters have to be diverted from sewer system, and standards and regulations have to be adjusted to cope with new pollutants and new applications.

2.3.2. *Desalination*

In Jordan, two main sources are available to be desalted: the red sea at the Gulf of Aqaba and brackish groundwater in Jordan Valley basins. Preliminary studies show that 50 MCM per year may be economically developable for domestic and industrial purposes from the brackish groundwater (JICA, 1995). For the case of seawater desalination at Aqaba, the transportation cost of fresh water from Aqaba which is located 350 km south of Amman is economically unfeasible.

Currently the Zara-Maeen reverse osmosis plant that will treat water that has a salinity of 1400-2000 mg/l is under construction. The plant will produce 47 MCM per year of drinkable water with a salinity of less than 250 mg/l. A pipeline will convey the brine to the Dead Sea. The construction of this plant is based on design-build-operate (DBO) concept.

2.3.3. *Mega-scale projects*

Two such projects are considered in the Jordan water sector investment plan:

1. The Red Sea-Dead Sea Project

The Dead Sea level is currently declining at a rate of one meter per year as a result of diverting most of Jordan River water out of it. If this continues, the decline will cause huge amounts of groundwater to flow to the Dead Sea. It is estimated that about 300 MCM per year of regional groundwater, half of which is fresh water, could enter the Dead Sea in about 50 years from now. The decline will also jeopardize the stability of the pond dikes, and its religious, archaeological and historical value of this unique international geographic feature. The project is a multi-purpose project that will convey 1.8 billion cubic meters of water per year through a water conduit some 180 kilometers from the Red Sea to the vicinity of the Dead Sea (WAJ, 2002). The Dead Sea has the lowest elevation on earth, about 400 m below the Red Sea level. The huge difference in elevation will generate enormous amounts of renewable energy that can be used to supply the reverse osmosis desalination plant that will be built at the Dead Sea location. The project will produce 850 MCM/year of fresh water; two-third will be delivered to Jordan and one third to Israel and Palestine. The resulting brine water will be directed to the Dead Sea, which will be sufficient to reverse the decline of its level and restore it at an ecologically prudent rate. The cost of the project is about 0.8 billion US dollars (MWI, 2002a).

2. The Disi-Amman Project

This project will supply additional high quality water to Greater Amman region from the deep nonrenewable fossil Disi Aquifer. A conduit will convey the fossil groundwater a distance of approximately 325 km from Disi aquifer towards the north up to Amman. The project will initially produce a minimum flow of 80 MCM/year (WAJ, 2002). The provision of this reliable additional water supply would relieve the upland and other aquifers used to supply Amman with drinking water from over abstraction. This will allow for partial restoration of the overexploited renewable groundwater resources in this area. The Disi-Amman project will also reduce the salinity of wastewater as the water from Disi aquifer has lower salinity than the water being used currently in Amman. This in turn will produce a better treated wastewater quality that can be used for irrigation to replace the valuable freshwater currently being used for irrigation.

3. Water Strategy and Policy in Jordan

A Water Strategy was formulated by the Ministry of Water and Irrigation (MWI) during the period 1995-1999 (MWI, 2002b). The strategy stresses the need for improved water resources management with particular emphasis on the sustainability of present and future uses, and protection against pollution, quality degradation, and depletion. The highest practical efficiency in the conveyance, distribution, and use of water resources shall be achieved. The strategy indicates that full potential of surface and groundwater shall be tapped to the extent permissible. Water with different qualities shall be investigated for use. Wastewater shall be collected and treated to allow its reuse in unrestricted agriculture and non-domestic purposes, groundwater recharge, or blending with freshwater. Water with marginal quality, brackish, and seawater sources shall be enlisted for desalination. The strategy has given priority to the basic human needs of a modest share of 100 l/capita/day, followed by tourism and industrial purposes, and lastly irrigation. The general trend is to limit irrigation demand by use of new technologies and changes in crops that consume less water and by shifting workers over time from, agricultural to industrial jobs where possible. The strategy also calls for dual approach of demand and supply management, high efficiency in water distribution and use, human resources development, and peaceful means to obtain Jordan's rightful share of those water resources shared by neighboring countries. In addition, full cost recovery of water supplied is not possible due to the high water cost (about 4.6 % of household income).

In addition to the Jordan's Water Strategy of 1997, a number of water policies and action plans were introduced. These are addressed below.

3.1. WATER UTILITY POLICY (1997)

The depletion of groundwater aquifers was assigned by the policy (MWI, 1997) as the major problem facing Jordan's water sector. This will put the sustainability of irrigation in the highlands and the desert in great danger. Therefore, legal and financial measures have to be implemented to gradually reduce groundwater withdrawals to the safe yield of aquifers. This may be achieved through planned use of fossil groundwater for municipal and industrial uses. The policy viewed wastewater as a strategic water resource that should be used in an environmentally sound manner. Industries will be encouraged to recycle part of their wastewater and to treat the rest to acceptable standards. Brackish water was considered to have the highest potential, among non-conventional resources, to augment the country's water resources. It can be used directly or after desalination. The policy indicated inadequate investments in distribution systems and lower efficiency than other services in the water supply sector.

3.2. GROUNDWATER MANAGEMENT POLICY (1998)

The policy stated that water withdrawal from the 12 water basins is more than their safe yield (MWI, 1998a). The over pumping ratio ranges between 146% in minor aquifers to 235% in major ones. The policy stresses the need to reduce the abstraction rate to the annual recharge by the year 2005. The policy recognized the importance of the Disi water for domestic use rather than the present agricultural consumption. Non-renewable groundwater sources shall be allocated to municipal and industrial uses as a first priority.

3.3. IRRIGATION WATER POLICY (1998)

The Policy (MWI, 1998b) considers wastewater as a resource of irrigation water. The policy allowed the highly subsidized fresh water to be used for irrigation only after municipal and industrial needs are met. The present water allocated for agriculture will not be diverted to other uses before providing a replacement source of water suitable for use in agriculture, unless cultivation endangers the sustainability of groundwater resources. This includes the potential depletion of groundwater from over pumping and/or the pollution of aquifers from agricultural chemicals and salts. The policy offers the farmers free leaching water out of surplus surface water during the wet season; especially to those using treated wastewater for irrigation in dry season.

3.4. WASTEWATER MANAGEMENT POLICY (1998)

The policy estimated the salinity of municipal wastewater to be about 580 mg/l, and average domestic water consumption to be about 70 l/capita/day, resulting in high organic load (MWI, 1998c). Due to evaporation, salinity increases in the effluent of waste stabilization ponds, which treated 85% of the total generated wastewater at that time. The policy considered the blending of treated effluent with relatively fresher water for suitable reuse. Disi water and other desalted water with lower salinity will replace partially the low quality groundwater consumed domestically. This will improve the quality of the treated wastewater in terms of salinity and other elements like chloride and sodium.

3.5. WATER SECTOR ACTION PLAN (2002-2006)

This action plan (MWI, 2002c) lists all issues related to water sector and the time schedule for the interval between 2002 and 2006. The action plan calls for greater private sector participation, and changing the role of the government. The plan stresses the need to enhance enforcement measures, and to establish new agricultural tariffs to reduce over drafting and illegal wells. The plan also contains recommendations for new wastewater and agricultural regulations.

The important issue in the plan is the agricultural water use. The MWI plans to limit the irrigated areas in the Jordan Valley to about 42,700 hectares to reduce water allocated for agriculture. In order to reduce groundwater abstractions, summer crops shall be banned in drought years. In addition, marginal water such as brackish and treated wastewaters are planned to gradually substitute fresh water used for agriculture. In addition, floods of the Jordan River are to be stored at Karama Dam and be used as brackish water for irrigation of salinity tolerant crops. In order to reduce water salinity of treated wastewater that is stored in King Talal Reservoir, the construction of a desalination plant at the reservoir is planned.

The Ministry gives a great attention to the cost recovery issue due to its economic importance. The ministry is committed to setting municipal water and wastewater tariffs at a level, which at a minimum will recover the costs of operation and maintenance. Recovery of capital costs also will become part of on-going pricing actions. The ministry will attempt to establish differential pricing for different qualities of water and end uses. Profitable markets (e.g., tourism, industry) will be expected to pay the full, fair water cost. The cost recovery will be achieved through water tariffs that will encourage the public to save water and consume less, and through the rehabilitation of the water supply systems which will reduce losses through the networks. In addition, efficiency of operation through employee reduction and training is essential. Public awareness campaigns were conducted as it is considered one of the main components for enhancing water conservation in Jordan.

The Government of Jordan intends to transfer infrastructure and services from the public to the private sector in order to improve performance and efficiency in the water sector. The principles of build/operate/transfer (BOT) and build/operate/own (BOO) are being considered, and has been implemented.

4. Water Demand Management

Despite the overexploitation of water resources, Jordan still has faced water shortages problems during the past few years in all sectors, especially in the summer season. The solution to this problem has been through introducing a number of measures to reduce demand. These measures are described below.

4.1. WATER CONSERVATION

Conservation in the domestic sector is practiced every summer through rationing program. Water is pumped to every area of the country once per week with around 24 hours pumping. Households have to store the water usually in tanks on the top of their houses to use it for the rest of the week. The short pumping period makes sure that not a very huge quantity of water can be stored in these tanks, and as a result one has to manage water demand so that this quantity of water is sufficient for the whole week.

The government has encouraged the use of water saving plumbing fixtures. The use of low flush toilets and displacement devices, such as a bottle placed in the toilet tank, can reduce the amount of water used during toilet flushing. Outdoor use for lawn watering or automobile washing using water hoses have been prohibited by law, although enforcement has not been put in place.

The government has started a number of projects to replace the old water supply networks with new ones, in addition to repair water leaks in the distribution system as quickly as possible. One problem of leakage in Jordan is that most of the country does not have elevated tanks and therefore pumping is used to distribute water. The high pressure in the mains close to the pumps causes many leaks, and elevated tanks have to be used. This is one option that the government is looking into to solve the problem. Water losses in the distribution system amount to about 50 percent. It is not known whether this is actually leakage or illegal or non-metered connections or errors in metering.

Agriculture is the largest water user sector; 66% of the total available water supplies are used for irrigation (MWI, 2000) and about 30% of this percentage is used for agriculture in the uplands. In the year 2000, about 540 MCM were used in irrigation, 40% came from surface water, 47% came from groundwater, and 13 % from treated wastewater. As domestic and industrial water uses increase, agricultural use of fresh water has to be reduced. In order to reduce the amount of irrigation water, the irrigation system in the Jordan valley has been converted to pressure pipe network (Committee, 1999). Drip irrigation is the main irrigation method used in the Jordan Valley (70 %) and in the uplands (90%). Sprinkler irrigation is only about 10%, and is being replaced by drip irrigation system. Shifting production to crops of low water consumption, and changing the irrigation practices are necessary. Replacing fresh water with marginal water, such as treated wastewater or brackish water should be accompanied by changing crops to salinity-tolerant crops. Much of the brackish groundwater can be used for irrigation of salt tolerant crops without desalination. Good management practices, such as mixing water resources, intermittent leaching, use of drip irrigation, brackish water use toward the end of the growing season, and avoiding irrigation during hot weather are essential in this case. About 70 to 90 MCM of brackish water can be safely withdrawn from aquifers on the eastern shores of the Dead Sea to irrigate salt tolerant crops (Committee, 1999).

Water use for industrial applications is only 5%. Groundwater use of large industries was about 35 MCM in the year 2000 (World Bank, 2001). Most large industries use water from their own groundwater wells and were largely unregulated. Recently the government imposed water use restrictions and pricing policies, together with wastewater quality requirements should motivate them to reduce their water use. In many industries in Jordan, water is being recycled to reduce the cost of water and the cost of wastewater treatment.

4.2. WATER PRICING POLICIES

The pricing of water should be designed to be fair; to ensure that water is allocated and used efficiently; and to recover the cost of delivery, operation, and maintenance. These objectives are usually conflicting and compromises have to be made. In water scarce regions, the price should be set equal to the marginal cost of supplying the last unit delivered (Committee, 1999).

Water pricing policies in Jordan has never been designed to reflect the true value of water. This has been caused by the high cost burden that consumers have to suffer if they pay the real cost of water. Despite this fact, water pricing policies have been put in place to reduce water consumption. For domestic use, water surcharges have been implemented to discourage excessive water use. For example, a household consuming 100 m^3 every three months would have to pay about 5.5 times the amount of money if only 50 m^3 were consumed, and about 22 times the amount of money if only 20 m^3 were consumed. This pricing policy has encouraged most consumers to consume only about 40–60 m^3 per household per three months as a maximum. As for industrial and commercial users, these pay a higher rate per cubic meter regardless of their consumption (about 1.4 US Dollars per cubic meter).

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URBAN WATER RESOURCES MANAGEMENT IN UKRAINE

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Abstract. Analyzed in the paper are outstanding issue faced by Ukraine in the area of urban water resources management, sanitation and water supply for population and economic needs in Ukraine. Paper is based on results of studies carried out in Ukraine by a number of international organizations, e.g. the World Bank, EBRD, DANCEE at which the author took a part as a local expert.

Keywords: sanitation; urban water supply; water resources; waste water management.

1. Outstanding Problems

The most important problems related to urban water resources management and water supply in Ukraine are:

- Poor drinking water quality, especially in smaller towns and rural areas of the country:
- Inefficient operation of water supply systems resulting in irregular drinking water supply,
- High energy costs, high water losses and constantly growing water tariffs.
- Contamination of water resources used for drinking water supply, recreation and fisheries.

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1.1. POOR DRINKING WATER QUALITY

According to the WHO in average 25 per cent of the samples of drinking water taken from piped water supply systems and private wells in Ukraine do not meet the EU water quality standards. According to results of local studies carried out in Ukraine in many regions show figures between 30-50 per cent of noncompliance for chemical parameters and 20-40 per cent for bacteriological parameters.

The vast majority of the regions with the highest non-compliance figures are located in the southern and eastern parts of the country. Another characteristic feature to be highlighted is that non-centralized water supply systems, which are mainly found in rural areas, perform much worse than centralized systems.

In all 12,233 people were infected by water transmitted agents during 1992-2001 according to the Ministry of Health of Ukraine. Most of the outbreaks occurred in the southern and eastern parts of the country. The poor drinking water quality seriously impacts on human health. Outbreaks of various diseases among the population due to poor drinking water quality are frequently reported in Ukrainian mass media. These deceases include cholera, virus hepatitis A, ontological illness, metabolic disorder, endocrine dysfunction, allergies and all sorts of skin diseases, including dermatitis and eczema.

1.2. INEFFICIENT OPERATION OF WATER SUPPLY SYSTEM

The water supply system – consisting of drinking water reservoirs, pumping stations, treatment plants and distribution systems – is relatively old. It dates back to the 60's and 70's. Furthermore, maintenance is inadequate. Consequently, breakdowns, leakages and scheduled water supply are common. These events seriously increase the risk for contamination of the drinking water.

In total, as much as 30 per cent of the abstracted water for drinking water supply is lost due to breakdowns and leakages on its way to the consumers. This figure is high in comparison with EU countries. In Denmark, it is 7 per cent. Unsurprisingly, the loss of water from the distribution systems due to breakdowns and leakages increases pumping and ultimately energy costs of the water utilities, measured as energy costs per m^3 of water supplied, considerably.

1.3. CONTAMINATION OF WATER RESOURCES

More than 80 per cent of total water abstraction is from surface water bodies (rivers, lakes and reservoirs).Groundwater plays a limited role. This picture will not change in future. Potential surface water resources are estimated at 210 km^3, whereas potential groundwater resources are estimated at 22 km^3 (Ukraine in figures, 2003).

Virtually all surface water bodies are officially classified as polluted or very polluted. Most important exceptions are the rivers of the Carpathians and Mountain Crimea.The environmental authorities are especially concerned about the contamination of the Dniepro river basin, since it provides drinking water for almost 75 per cent of the Ukrainian population.

Surface water bodies are mainly polluted with compounds of chromium, manganese, nitrogen, sulfate, oil product and pesticides. Increased concentrations of phytoplankton are experienced every year during the summer time.

It is particular alarming that monitoring of surface water quality shows that despite of the significant decline in industrial production and the consequent decrease in waste water discharges, the environmental condition of the receiving waters has not improved.

For example, many people in Sevastopol claim that they are afraid to drink water from the tap because it comes from the Dniepro river, which they fear is seriously polluted due to the Chernobyl accident (GEF, 1997). In fact, it is not. Such environmental psycho stress seems widespread in Ukraine.

The Chernobyl' accident added to the pollution of surface water bodies, foremost the catchments basins of Prypiat and Dniepro rivers. Furthermore, floods in the 90's increased the concentration of radio nuclides in these. In recent years, however, the concentration of radio nuclides has remained stable. In most parts of the rivers concentration levels are not dangerous to human health. Nevertheless, many Ukrainians are afraid to drink water from these.

Distribution of the groundwater is very uneven due to the geological and hydro-geological formations, and the smallest amount of potential groundwater is found in the southern and eastern regions, which also have the smallest amount of available surface water bodies. At the same time these regions have the highest water consumption mainly due to level of industrialization. The availability of surface waters amounts to 140-550 m^3 per capita in the southern and eastern regions and to 700-6000 m^3 per capita in the northern and western regions (Draft Environmental Performance Review of Ukraine, 1999). An increasing amount of groundwater does not meet the standards, whether Ukrainian standards or EU standards. Groundwater is polluted with compounds of nitrates, high salt content, pesticides, fluorine, iron manganese and bromine and barium; the latter is experienced in Lugansk and Donetsk regions.

2. Historical Roots of the Current Problems

2.1. POOR DRINKING WATER QUALITY

The poor drinking water quality is, to a large extent, caused by the deterioration of the physical infrastructure, such as pumping stations, treatment plants and distribution systems, throughout the 80's and 90's. Much needed investments have not been carried out. Furthermore, most water utilities have not even been able to cover the required operation and maintenance costs.

Virtually nobody in Ukraine drinks water directly from the tap. Some people boil the water before drinking. Doing this they try to eliminate chlorine and bacteria. Others buy bottled water. In any supermarket one can buy 10 liters bottles of plain water.

There are, however, other important reasons why drinking water quality is notably poor. These include contamination of rural water resources from, especially, agricultural production and insufficient monitoring and enforcement.

Chemical and bacteriological contamination of rural water sources constitutes a serious problem. Many of the approximately 127,000 sources of non-centralized water systems monitored do not meet established water quality standards, whether Ukrainian standards or EU standards. The quality of the groundwater used without any treatment by most part of the rural population is even worse. Nitrate contamination is increasing due to uncontrolled use of mineral and especially organic fertilizers at the private and collective agricultural farms. Furthermore, rural water supply systems are often in a very poor condition compared to urban water supply systems. Non-centralized water supply systems are in a particular bad condition. So the rural population is hard hit.

In August 2001, a hepatitis A outbreak hit a western Ukrainian village, sending 20 people, including three children, to the hospital after drinking polluted well water (Mama 86, UNED-UK, 1998). The victims, all from the village of Korotyshyn in the western Lviv region, arrived at the local hospital with poisoning symptoms the Ministry of Emergencies informed the press. Medical officials said the poisoning was caused by sewage that seeped into the village's wells. Symptoms of hepatitis A include nausea, vomiting, and jaundice and range from mild to severe.

Insufficient monitoring and enforcement constitute another serious problem. It is very much linked with the existing system of water quality standards, which dates back to the Soviet Union. The water quality standards are, as already mentioned in Chapter 2, very strict compared with EU standards. They are based on a goal of zero damage to human health and also ecosystems, totally ignoring the technical and economic feasibility of meeting these. The methodology for establishing the water quality standards is still based upon the water quality standards for fishery. That is, almost all water bodies are designated for fishing use, a category subject to most stringent requirements as can be seen from Table 1. It is almost impossible, not only to meet the standards, but also to monitor them. In the words of the EAP TF Secretariat: "In fact, the mandated concentration limits for pollutants in the NIS countries are so low that they cannot be detected by the available monitoring equipment. Requirements that are impossible to meet and monitor are not easy to enforce.

TABLE 1 Selected water quality standards for protection and support of fish life in Ukraine, Russia, Kazakhstan and the EU

Parameter	Russia	Ukraine	Kazakhstan	EU (78/659/EEC for salmonid fish)
BOD5, mg/l	3-6	2	3	3
Suspended solids, mg/l	Background + 0.75			25
Copper, mg/l Cu	0.005	0.001	0.001	0.04
Zinc, mg/l Zn	0.01	0.01	0.001	0.3

2.2. INEFFICIENT OPERATION OF WATER SUPPLY SYSTEM

The water sector, including the waste water sector to be dealt with in Section 3.3 below, is in a critical condition. It suffers from many years of insufficient investments in infrastructure renewals, combined with oversized and outdated equipment. Most facilities are constructed 20-40 years ago without taking into consideration the need to minimize operation and maintenance costs, including energy costs. Pipes, pumps and other physical infrastructure have not been upgraded or even maintained properly for decades. As a result, the infrastructure for a number of years has been and still is rapidly deteriorating, which has implied that the citizens of Ukraine in these years are experiencing a severe reduction in the quality of the water services provided. Probably, the negative effects this has had on human health and ecosystems as well as the strain that has been put unnecessarily on the country's natural resources cannot be overestimated.

The present urban water supply and management systems are characterized by:

- Insufficient water resource protection, partly due to insufficient sludge treatment and disposal.

- High energy consumption caused by oversized and inadequate pipe layout at pumping stations, old and low efficient pumping systems, lack of proper pressure zoning.
- Very poor condition of pipe networks and hydraulic imbalances in network resulting in unacceptable high water losses in network, insufficient pressure and poor water quality.
- Insufficient metering of water abstraction, supply and consumption.
- No incentive for water utilities to aim at water and energy conservation.
- The water utilities still rely on a "produce and sell" approach instead of a "sense and respond" approach, where the customers are in focus.

The high water consumption that exists side by side with breakdowns, leakages and scheduled water supply may be explained by the above-mentioned low level of tariffs levied on the enterprises and households and also the general lack of individual water meters. Furthermore, it may be explained by the fact that the existing hot water system often serves several households or even entire residential zones, which makes it necessary for the individual household to release a large volume of water before the heated water arrives at the household. This problem also contributes to high costs for the central heating of the water. Generally speaking, there is a limited focus on water conservation in Ukraine.

2.3. CONTAMINATION OF WATER RESOURCES

Since 1990 total water abstraction has decreased by nearly 50 per cent. Surface water and groundwater abstracted have decreased by 50 and 43 per cent, respectively. As a rule, surface water bodies constitute the greater share of total water abstraction in Ukraine.

The far most important reason for this decrease is the output decline within industry and agriculture. It is not owing to increased efficiency in water use.

There are several reasons for the experienced worsening of the groundwater quality throughout the 90’s. The most important of these are the following:

- hydrogeological conditions (hardness and also content of solid residual, iron, manganese, fluorine, ammonia, chlorides and others);
- overexploitation; and
- contamination due to infiltration of pollutants through the discharge of untreated waste water on the ground, leachate from waste dumps, inappropriate handling of pesticides and chemical fertilizers, spread of

liquid wastes from animal farms, draining of water from mines to lower aquifers and leakages from large jet fuel and oil storage facilities within the military.

In many cases, the present groundwater quality necessitates advanced treatment of the water before consumption. Groundwater with iron content of 1-5 mg/l or manganese content of up to 1.0 mg/l, as is found, requires advanced treatment.

3. What Should be Done?

3.1. SEARCH FOR INVESTMENT SOURCES

The most urgent investment needs regarding water resources and water supply taking into consideration the above-mentioned problems concern the following:

- Upgrading of the physical infrastructure, such as pumping stations, treatment plants and distribution systems, including hot water systems.
- Installation of individual water meters.
- Upgrading of equipment for monitoring water quality, leakages and energy consumption in order to document needed improvements.

Total capital cost requirements of achieving 24-hour supply service level and also fulfilling the EU water quality standards with a national coverage of 78 per cent for centralized water supply have been estimated at EUR 15 billion. It covers the connection of an additional 6.6 million people to centralized water supply; this capital cost requirement alone has been estimated at EUR 1.5 billion.

Anticipating a spread of the investments over a time horizon of about 20 years, the average cost per capita totals EUR 25 per year, corresponding to EUR 340-400 per capita for the entire period from 2003 to 2022.

Total capital cost requirements of improving the operational safety of the centralized water supply system has been estimated at EUR 3-4 billion EUR. It is envisaged that investments may be carried out from 2003 to 2010. The average cost per capita totals EUR 80-110 for the entire period from 2003 to 2022.

3.2. UPGRADING OF THE EXISTING LEGISLATION

The environmental policy reform initiatives in Ukraine within the water sector address the above-mentioned problems fairly well. Consequently, it is important in the short to medium term to ensure further progress in the development and successful implementation of these initiatives.

In doing this, there is a need to pay special attention to the water resource classification scheme, water quality standards, water utilities' management and operation and relevant international environmental agreements. Furthermore, there is a need to eliminate existing contradictions, voids and uncertainties within the legal framework and also to focus the required secondary legislation.

The legal framework regarding the water utilities' management and operation needs a complete overhaul. Most important is to ensure decentralization and commercialization of the water utilities. They should operate with managerial and accounting independence from municipalities, full cost recovery through water tariffs should be introduced, and they should be allowed to cut-off customers, who do not pay.

Two international environmental agreements are of particular importance since they pose Ukraine with some additional challenges but also offer some possibilities. These are the Convention on the Protection and Use of Trans-boundary Watercourses and International Lakes, which Ukraine has ratified, and the Protocol on Water and Health, which Ukraine has signed but not yet ratified.

As much as 75 per cent of Ukraine's rivers are trans - boundary. Thus, they constitute an important area for regional co-operation in accordance with the Convention on the Protection and Use of Trans-boundary Watercourses and International Lakes. Ukraine has specific agreements on transboundary waters with the Belarus, Moldova, Poland, Slovakia and Russia (see Suggested priorities for environmental protection and natural resources management, Ukraine, World Bank References CH 9). Furthermore, several international projects aimed at fostering co-operation in water quality monitoring and assessment are being carried out – some between Ukraine and Belarus/Poland in connection with the Bug river basin, others between Ukraine and Slovakia in the Latoritza and Uzh rivers. It is important to further strengthen this regional co-operation in transboundary river basin management not just on the technical, but also on the administrative level. Here the EU Water Framework Directive may serve as a valuable source of inspiration to all parties involved. It focuses on river basin management plans as best models for a single system of water management instead of according to administrative or political boundaries.

It is envisaged that Ukraine will ratify the Protocol on Water and Health in the near future. Then, Ukraine has to take appropriate actions aimed at ensuring:

- adequate supplies of wholesome drinking water;
- adequate sanitation to a standard that sufficiently protects human health and the environment;
- effective protection of water resources used as sources of drinking water and also of their related water ecosystems;
- adequate safeguards for human health against water-related diseases; and
- effective systems for monitoring and responding to outbreaks or incidents of water-related diseases.

3.3. INTRODUCTION OF NEW REGULATORY FRAMEWORK AND ITS ENFORCEMENT

In order to meet the challenges that follow from the problems regarding water resources and water supply it is important that the environmental authorities and water utilities are capable of designing and carrying out certain measures.

The water utilities should introduce international accounting standards, management information systems and also performance based service contracts or private sector involvement through specially designed management contracts. Certainly, excessive top management and staff training will be needed.

The introduction of full cost recovery through water tariffs at the water utilities constitutes a separate challenge that has to be properly addressed by the environmental authorities, water utilities and others. Care should be taken to ensure that customers can afford to pay. In Kiev, for instance, it will be difficult to increase the water tariffs for residential consumers, as they already amount to more than four per cent of their expenditures. Here it makes sense to make a special effort to lower water consumption, while at the same increasing water tariffs. In general there is a need to introduce measures providing social protection for the vulnerable, including a better targeting of social benefits.

Energy costs constitute the most important cost component in most water utilities. Current pump equipment is often too large and inefficient. Large-scale energy savings are possible through rehabilitation of pumping stations. Water conservation will reduce the energy costs and also reduce investments in rehabilitation and renewal of pumping stations.

Public awareness should be much further improved through, among others, improved transparency in monitoring. It is important that the general public knows about possible impacts on environment and human health of the pollution of water bodies (The Law of Ukraine on maintaining population sanitary and epidemic welfare, 1994). Likewise, it is important that the general public knows about the pollution levels. Improved information about pollution levels will not only promote public awareness and thereby pollution mitigation but also diminish existing environmental psycho stress, which seems widespread in Ukraine.

4. Conclusions

The water sector has for several years faced several obstacles to development. Physical water supply and waste water facilities have deteriorated to a degree where substantial investments are required simply to stop further deterioration.

The system of effluent limit values, including the waste water treatment plant's effluent limit values, does not promote sufficient treatment of waste water. On the contrary, it makes monitoring and enforcement regarding waste water almost impossible. The problem is that the effluent limit values for individual polluters, which are established in permits based upon the water quality standards, are so strict that they are quite impossible to enforce. In comparison with the EU legislation they are even stricter than the water quality standards. Consequently, so-called temporary effluent limit values, which are not envisioned in the legislation, and which are negotiable on a case by case basis as part of the permitting process, are used in practice, thereby increasing the discretionary power of the environmental authorities. They are much less strict than the EU discharge limits. Though they are claimed to be temporary they are, in fact, not.

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WATER SUPPLY, URBAN DRAINAGE AND WASTE WATER TREATMENT IN THE ORAVA REGION

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Abstract. Project solves water supply, wastewater collection and waste water treatment in the whole Orava region, by achieving following goals:

- Ensuring water supply by drinking water given quality at the Orava region.
- Improvement of pressure condition in drinking water network
- Water leakage decreasing
- Ensuring the collection and treatment of waste water at the agglomeration above 2000 PE.

Keywords: regional project; sewer reconstruction; water supply; waste water treatment.

1. Basic Project Information

On a Slovakian average, currently some 82% of inhabitants (c/a. 4.4 mil.) living in 67% of settlements are supplied by piped water and about 55% of inhabitants are connected to public sewerage networks. Presently, the three districts of the Orava region – Námestovo, Dolný Kubín and Tvrdošín belong to those with the lowest ratio of population connected to public water supply and sewerage systems (except the district of Tvrdošín). The district of Námestovo belongs to those few districts in Slovakia, where the connection ratio to public sewerage is below 30% (see Figure 1).

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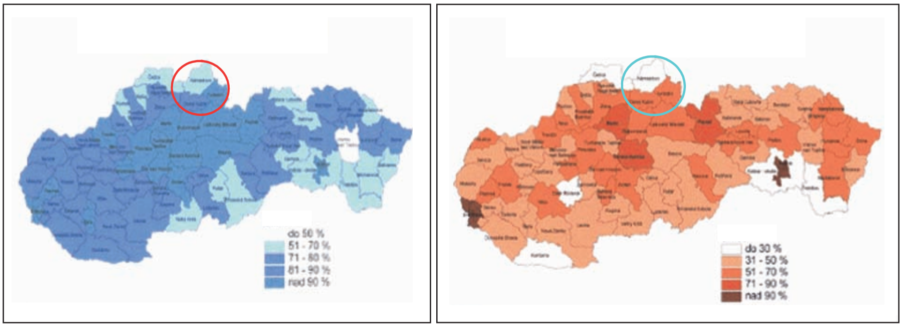

Figure 1 Current situation in water supply and sewerage in Slovakia

The project deals with water supply and sewerage of the Orava region. The region, with an area of 1,700 km^2, is located in North Slovakia and is spread over 3 districts with a total of 59 municipalities, including 4 towns and 59 villages. The total population of the region is 121,000.

The overall objectives of the project are the following:

- Achievement of compliance with EC Directive 98/83/EEC on the Quality of Water Intended for Human Consumption (Drinking Water Directive) and EC Directive 91/271/EEC on Urban Waste Water Treatment (UWWT Directive),
- Safeguarding the quality of water in the Orava, Biela Orava, Polhoranka and Váh rivers, and
- Support of economic development of the Orava region.

The overall objective will be reached by construction of water distribution networks and sanitary sewer systems resulting in connection of inhabitants currently not connected to piped water, as well as to collection and treatment of all collected waste water at central WWTPs (including advanced nutrient removal currently not applied in any of the WWTPs in the project area).

2. Project Location and Scope

The project area represents one hydrographical unit. Almost all streams in the area belong to the Orava River Basin. Moreover, on the top of Oravské Beskydy on the Slovak–Polish boarder, the main European watershed distributing line between the Baltic and Black see can be found.

The river network in the Orava river basin is formed by the Orava River and its tributaries. The Orava River has two main tributaries: Biela Orava (White Orava River) and Čierna Orava (Black Orava River – only in Poland). Their confluence used to be in the municipality of Ústie, a village flooded on purpose by the lake.

The Orava lake is a dominant phenomenon in the region with an area of 35 km^2 and volume 350 mil. m^3. Its primary purpose is river regulation, generation of hydro-energy and flood protection. Among the various tributaries of the Orava lake, Biela Orava, Mútňanka and Polhoranka rivers are classified as waters used for drinking water abstraction. Although the Orava lake itself is not used for drinking water abstraction, its primary use is for hydro-energetic purposes and flood protection, it is widely used for recreational purposes. Therefore one of the goals of the project is maintenance of its good quality.

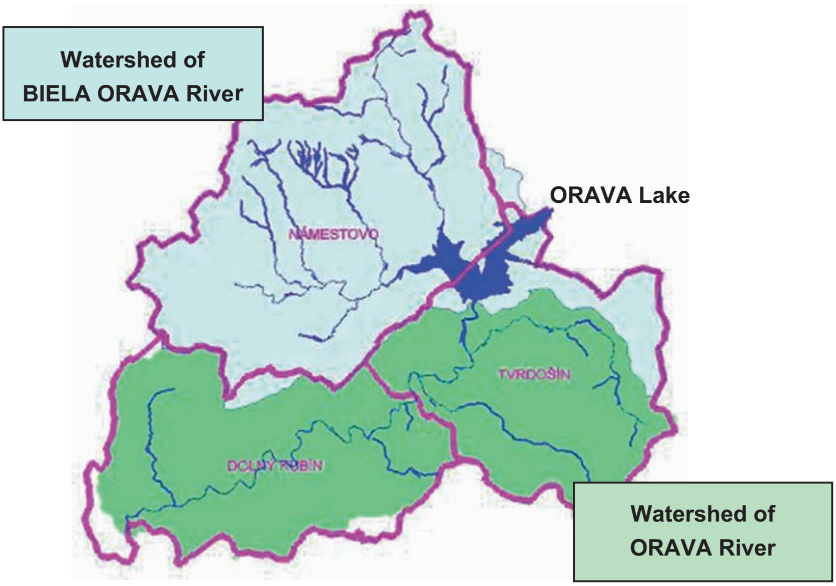

Figure 2 Project area The Orava River Basin

TABLE 1 Basic demographic data

Data	District			
	Námestovo	Dolný Kubín	Tvrdošín	Total
Area – km^2	690	490	479	1 659
Inhabitants	49 304	38 028	33 281	120 613
No. of cities	1	1	2	4
No. of villages	23	23	13	59

TABLE 2 Connection to the public sewer system

District	Living inhabitants	Connection to public sewer system 31.12. 2003	
	Number	Number	%
Námestovo	49 304	8 533	17,3%
Dolný Kubín	38 028	19 847	52,2%
Tvrdošín	33 281	19 498	58,6%
Total	120 613	47 878	39,7%

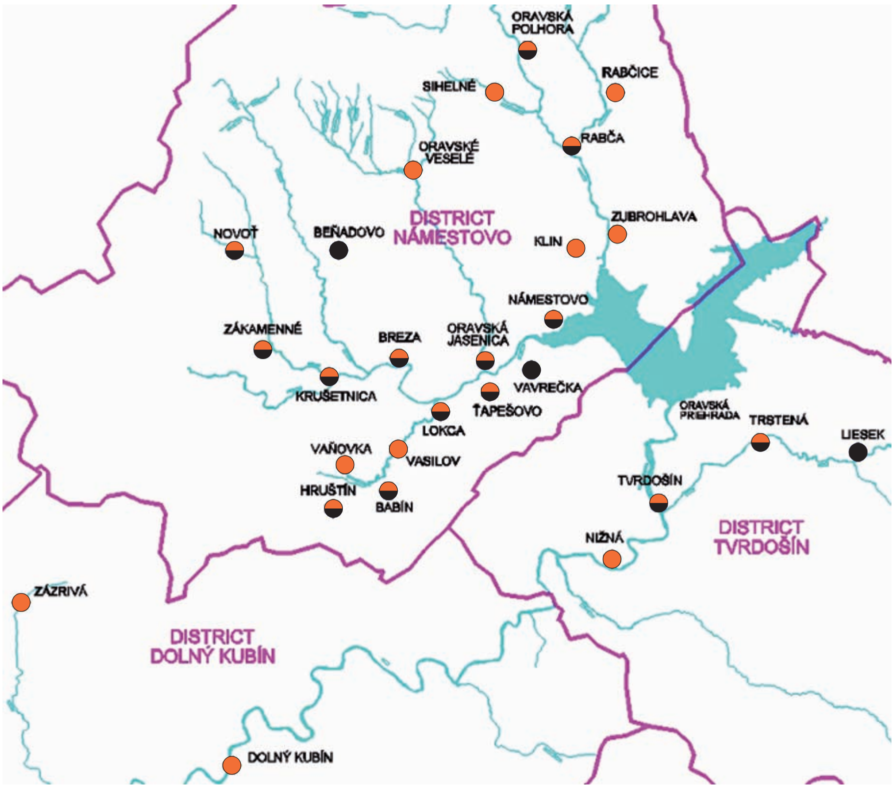

Figure 3 Project area (● - water supply, ● - sewerage)

3. Water Supply

Provision of the inhabitants and other water users in the district of Námestovo with adequate quantities of mains water complying with Slovak and EU quality norms. This will be reached by extension of the existing drinking water distribution network “OSV” (= Oravský skupinový vodovod) through construction of a new delivery system for 10 municipalities in the project area. Only the village of Babín will not be connected to the OSV, this municipality will be supplied from sources located in Hruštín. It is estimated that by 2030 an additional population of 18,282 (compared to current state) would be connected to new water distribution networks.

4. Urban Drainage and Waste Water Treatment

Construction of sanitary sewer systems for 18 municipalities. This will result in connection of an additional 32,766 inhabitants by 2009 to new sanitary sewage systems.

Reconstruction of some sections of the existing combined sewerage in the towns of Námestovo, Nižná, Tvrdošín, Trstená.

Reconstruction and extension of the existing WWTP in Dolný Kubín, design PE 23,000 and WWTP in Nižná, design PE 33,000 (design period 2030).

Intensification and extension of the existing WWTP in Námestovo, design PE 42,000 (design period 2030).

New WWTP with design PE 3,400 in Zázrivá (design period 2030).

All WWTPs will be capable of receiving and treating cesspit waste (septage), thereby enabling the practice of spreading untreated waste on land to be reduced.

The total population connected to sewer systems and biological WWTPs will reach 85,796 in 2009 and will raise to 89,084 by 2030.

The expected results/benefits of the project are:

- Supply of sufficient quantity and good quality drinking water to 59,549 inhabitants in total, out of which 8,651 will be newly connected;
- Connection of additional 32,766 inhabitants to sanitary sewerage, resulting in reduction of untreated pollution entering ground and surface waters through leaky cesspits and direct outflows to the local streams and the receiving waters; additional pollution removed annually in the project area: 1,092 tonnes BOD_5 (27% reduction compared to 2003), 152 tonnes N_{tot} (21% reduction compared to 2003), and 49 tonnes of P_{tot} per year (40% reduction compared to 2003);
- Reduction of operation and maintenance costs;
- Promotion of economic development of the region, increase of land value.

The following supporting documents have been compiled during the preparation of the application:

- Feasibility Study (current material)

- Environmental Impact Assessment Studies
- Financial and Economic Analyses
- Preliminary Construction Design (for the purposes of state expertise)
- Site Permission Design
- Construction Permission Design (under development)

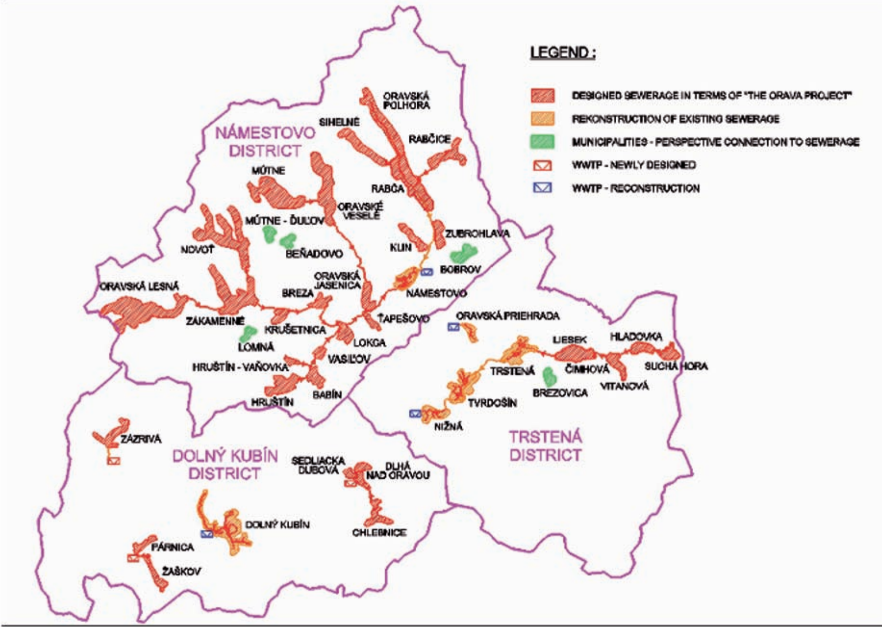

Figure 4 Agglomerations

4.1. SEWERAGE

4.1.1. *General approach*

It is proposed to construct a sanitary sewer system with central waste water treatment at the existing WWTP in Námestovo (after extension).

The extent of the proposed sewers was consulted with the mayors of all included municipalities. Sewers were proposed only in those areas where there was a high probability that inhabitants would connect to the constructed sewers. Remote locations were kept unserved. After the definitive version of lengths mayors provided for the consultant the exact number of house connections to be included in the project. Thus, the proposed design represents 81% connection of inhabitants to the sewer system in 2009 in the municipalities included in the project.

Remote dwellings not included in the present design study will have to be solved on an individual basis either by construction of local WWTPs, cesspits or septic tanks and disposal of pre-treated waste water at WWTP Námestovo. Construction of cesspit receiving stations at the new sewer system can also be considered, however, these places might be exposed to elevated smell in the summer period.

TABLE 3 Project activities

Activity	Description of activity	Length/No.	Addtl. inhab. connected by 2009	Total affected inhab. by 2009
Water supply	Reconstruction of existing water supply systems in the project area:		18,282*	55,128
	- reconstruction of supply network	24 km		
	- reconstruction of storage tanks	11 pcs		
	Extension of the existing water supply system into new municipalities:			
	- new water distribution network	57 km		
	- new water storage tanks	7 pcs		
	- new pumping station	3 pcs		
	- new service connections	21 pcs		
Sewerage	Construction of new sanitary sewer systems:		32,766	85,796
	- new sanitary sewers	234.2 km		
	- new combined sewers	1.7 km		
	- new service connections	7,830 pcs		
	- new pumping stations	36 pcs		
	- new pressure pipes	22.1 km		
	Reconstruction of existing combined sewerage in Námestovo, Nižná, Tvrdošín, Trstená due to structural reasons			
	- combine sewers	13.1 km		
	- pressure pipes	0.3 km		
	- pumping stations	1 pcs		
	- service connections	0.6 km		
Waste water treatment	Extension/upgrade of the WWTPs in Námestovo, Nižná and Dolný Kubín	3 pcs	30,905	83,439
	Construction of a new WWTP in Zázrivá	1 pc	1,861	2,357

* inhabitants connected to central water supply system

4.1.2. *Design of sanitary sewage systems*

For the purposes of waste water collection the district of Námestovo can be divided into two regions.

The newly proposed sanitary sewer system in the Polhoranka River Basin (Klin, Zubrohlava, Rabča, Rabčice, Oravská Polhora, Sihelné) will be connected to the existing main sewer Námestovo – Rabča, put into operation in 2004. Waste water from these municipalities will be pumped by pumping station ČS Klin to WWTP Námestovo. Thus, waste water from this part of the project area will not come into contact with the sewer system of Námestovo.

In the catchment area of the Biela Orava River the municipalities of Ťapešovo, Oravská Jasenica, Lokca, Vasilov, Babín, Hruštín, Oravské Veselé, Breza, Krušetnica, Zákamenné and Novoť have been included into the design. As with the other catchment, a by-pass of the combined sewer system of Námestovo has been proposed and sewage will be pumped directly to WWTP Námestovo.

The amount of waste water from the Biela Orava catchment is three times higher than the amount of waste water from Námestovo. Should this amount be connected to the existing sewer system of Námestovo (sewer A) and consequently to ČS Námestovo, it would be necessary to ensure a dilution ratio of 1:4 at Q24 of 225 l/s. This would required reconstruction of ČS and the pressure pipes as well. From this reason a by-pass of this section was proposed with direct pumping to WWTP Námestovo.

The second main reason of this choice was to minimise the possible negative effects to the Orava lake during overflows from the combined sewer system.

The project does not include two large villages, namely Oravská Lesná and Mútné, these villages did not agree with their inclusion in the project. However, both sewers and pumping stations were designed to able to accommodate waste water from these villages, too, should they decide to connect to the system in the future.

Waste water from the villages of the Biela Orava basin will be carried through proposed main sewers Námestovo-Lokca-Novoť and Lokca-Hruštín to WWTP Námestovo. Waste water from the Polhoranka basin will be carried to the existing sewer Námestovo-Rabča and will also be treated at WWTP Námestovo.

4.1.3. *Assessment of the combined sewer system in Námestovo*

A reconstruction of sewer A has been proposed. This sewer exhibits elevated amounts of infiltration water. The pressure pipe DN 400 to Námestovo will be placed in the same ditch with the reconstructed sewer A.

4.1.4. *Pumping station Námestovo*

Reconstruction of the existing pumping station has been proposed. Design discharge of 60 l/s has been selected and two submerged pumps will be installed at the pumping station. Mechanically raked screens are also part of the project. The maximum inflow to the ČS is 90 l/s, a retention time of 35 minutes will be ensured in the accumulation chamber. The dimension of the pressure pipe is DN 300 mm and will deliver waste water to the existing sewer system. Capital costs were calculated of price level 2003.

TABLE 4 Municipalities/inhabitants connected to new sewerage within the project

No.	Municipality	Inhabitants 2003		Inhabitants 2009		Inhabitants 2030	
		Total	Connect.	Total	Connect.	Total	Connect.
1	Námestovo	8,100	6,860	8,187	6,860	8,494	7,117
2	Klin	1,988	388	2,009	1,617	2,085	1,677
3	Zubrohlava	2,000	23	2,022	1,647	2,097	1,709
4	Rabča	4,260	83	4,306	3,516	4,467	3,647
5	Rabčice	1,820		1,840	1,146	1,908	1,189
6	Oravská Polhora	3,588		3,627	2,931	3,762	3,041
7	Sihelné	1,997		2,019	1,632	2,094	1,693
8	Ťapešovo	603		610	537	632	557
9	Oravská Jasenica	1,517		1,533	1,269	1,591	1,317
10	Lokca	2,159		2,182	1,828	2,264	1,897
11	Vasiľov	778		786	615	816	638
12	Babín	1,384		1,399	1,155	1,451	1,199
13	Hruštín	3,172		3,206	2,603	3,326	2,700
15	Oravské Veselé	2,702		2,731	2,243	2,833	2,326
16	Breza	1,512		1,528	1,273	1,585	1,321
17	Krušetnica	928		938	788	973	817
18	Zákamenné	4,902		4,955	4,091	5,140	4,244
19	Novoť	3,106		3,140	2,508	3,257	2,602
	Total	46,516	7,354 16 %	47,018	38,259 81 %	48,777	39,690 81 %

4.2. WWTP NÁMESTOVO

4.2.1. *Proposed technology*

During the construction of main sewer Námestovo – Rabča the first stage of reconstruction of WWTP Námestovo was carried out in 2002/2003 for a design capacity of 15,000 PE. It is proposed to increase the PE of the WWTP to 42,000 within this project (second stage), where reconstruction of the mechanical treatment unit, biological line and sludge management unit has been considered. In the third stage of reconstruction the WWTP may be extended to a capacity of 63,000 PE. The mechanical treatment and sludge management units will have this capacity after the second stage of reconstruction.

4.2.2. *Mechanical treatment*

Waste water will flow from the division chamber to the technological line of WWTP. The division chamber will serve for by–pass of the WWTP connected to the new storm sewer discharging storm water from the combined sewer overflows located upstream.

Downstream of the division chamber we can found the sampling place. The current object of mechanical pre-treatment will be removed. At the same place, a new screening room will be erected. Screens will be equipped by press and screenings will be transported to a container.

Two vertical grit chambers will be constructed for a maximum flow of 320 l/s. The mixture of sand and water will be pumped to a sand washer located in the screening room. Washing the sand will ensure reduction of organic content below 3%.

The next object is a new circular sedimentation tank for removal of suspended solids. The diameter of the tank is 17.5 m and is equipped with floating matter removal mechanism. Primary sludge from the tank will be pumped to the digester. In case of insufficient organic matter it will be to stop temporarily the sedimentation tank. In the third stage it is proposed to construct a second primary sedimentation tank.

From the sludge holder the supernatant will be taken back to biological treatment. Maximum design flow of the biological line is 190 l/s. Higher flows during storm events will be diverted to a storm retention tank with proposed retention time of 35 minutes. Water from the tank will be pumped to the inlet pumping station. The tank will be cleaned by a tipping bucket mechanism.

4.2.3. *Biological treatment*

The biological treatment line was designed as a low-rate activated sludge process enabling reduction of nitrogen – denitrification.

Simultaneous nitrification and denitrification will take place in the activated sludge tank. This will be ensured by proper aeration of the tank and through monitoring of the oxygen content by an oxygen probe connected to the central SCADA system. During anoxic conditions (i.e. no aeration) the mixed liquor will be kept in suspension by low-rate mixers. Phosphorous removal is ensured through chemical precipitation and sedimentation of the flocs in the secondary sedimentation tanks. The precipitating agent will be dosed to a manhole prior the secondary sedimentation tanks.

Waste water from the activated sludge tanks will flow through a division chamber to two secondary sedimentation tanks. Here separation of activated flocs from water will take place. Treated water will flow to the outlet flume. Return sludge will be pumped back to the flume before the activated sludge tank.

4.2.4. *Sludge management*

Primary sludge will be pumped from the primary sedimentation tank to a sludge digester. The concentration of activated sludge in the activated sludge basins will be kept at 4 kg/m^3. Excess sludge will be pumped to the sludge thickener. Sludge after thickening to 50 kg/m^3 will be pumped to the sludge digester where it will be anaerobically stabilised at mesophilic conditions (cca. 40 °C). Thermal exchanger will be used for keeping the temperature at the selected level. Stabilised sludge will be dewatered at a centrifuge with the final water content of 25%. Dewatered sludge will be stored under a covered storage place. It will be hygienised by lime and may be used for composting.

5. Economy & Financing

TABLE 5 Investment costs (excl. VAT)

Cost item	Costs in (MSKK)	Costs in (MEUR)	(%)
Land	2.227	0.054	0.1
Site preparation	77.838	1.898	2.5
Main works	2 370.478	57.817	76.6
Machinery	224.104	5.466	7.2
Design	75.42	1.840	2.4
Publicity	6.486	0.158	0.2
Supervision	129.729	3.164	4.2
Contingences	207.567	5.063	6.7
Total	3 093.853	75.460	100.0

It is assumed that expenditure will be phased in the particular years as it is shown in Table 6.

TABLE 6 Phasing of Capital Expenditure (excl. VAT)

Year	Scheduled Expenditure (MSKK)	Scheduled Expenditure (MEUR)	(%)
2005	228.457	5.572	7.4
2006	1 055.672	25.748	34.1
2007	1 055.672	25.748	34.1
2008	754.052	18.392	24.4
Total	3 093.853	75.460	100

6. Conclusions

Regional projects for water protection are complex, complicated, multidisciplinary and long time projects. They are politically important with complicated relations among authorities, both at the local and international level. Close corporation of all involved parties and companies is absolutely necessary.

Technical analysis must be designed in short time, therefore it is necessary to use effective tools. Simulation of the sewer system behaviour is very useful for this phase of the project. The results of simulation are necessary for investment scale definition. Working system model is the base for following detail master plan concept guaranteeing optimal maintenance of the system.

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CHALLENGES IN URBAN WATER SUPPLY

ROBUST DESIGN AND MANAGEMENT OF WATER SYSTEMS: HOW TO COPE WITH RISK AND UNCERTAINTY?

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Abstract. The implications of uncertainty in input data and model parameters are not always understood or considered when designing urban water systems. There is an obvious need to develop design methods that can model uncertainties and produce 'robust' designs. These designs should provide adequate service to customers despite fluctuations in some or all of the design parameters. This paper presents a general methodology for robust design of such systems. The methodology is based on closely integrating reduced Monte-Carlo sampling with multiobjective Genetic Algorithms. An application to the New York Tunnels rehabilitation problem illustrates the effectiveness of the methodology. The results show that the robust design methodology presented here seems to be capable of identifying Pareto optimal fronts for uncertain input variables while achieving significant computational savings when compared to the full MC sampling technique.

Keywords: water systems, design, rehabilitation, optimization, uncertainty

1. Introduction

The implications of uncertainty in input data and model parameters are not always understood or considered when designing urban water systems. Similarly, decision-making for water distribution and sewer system rehabilitation has large, long lasting consequences and is fraught with risk and

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uncertainty. For example, uncertain information about the condition and hydraulic performance of the existing systems could lead to their future inadequate performance due to them being oversized, undersized or even obsolete. Therefore, there is a need to develop design methods that can model such uncertainties and produce 'robust' designs. Here, robustness of a system is defined as its ability to provide adequate service to customers despite fluctuations in some or all of the design parameters.

Uncertainty is also a term that has caused much controversy among scientists. In this paper the definition of Korving et al. (2002) is used where two types of uncertainty exist: inherent and epistemic. Inherent (or aleatoric) uncertainty consists of random fluctuations that are intrinsic to the problem being studied (e.g. temporal/spatial water demand variability); this type of uncertainty is irreducible and is usually characterized using statistical tools, e.g. probability density functions (p.d.f.). Epistemic uncertainty results from a limited knowledge of fundamental phenomena, e.g. rainfall-runoff processes or in-sewer processes.

The problem of stochastic (i.e. robust) water distribution system optimization is formulated and solved here to illustrate urban water system optimization under uncertainty. Although the test case presented in this paper considers a design problem, the methodology is general and could be applied to rehabilitation and/or operations management of an urban water system, i.e. both clean and wastewater.

1.1. STATE-OF-THE ART IN WATER NETWORK OPTIMIZATION

Water distribution system design optimization is one of the most heavily researched areas in the hydraulics profession (see Lansey, 2000 for detailed review). Design of new water distribution networks is often viewed as a least-cost optimization problem with pipe diameters, tank characteristics and pump characteristics being the most commonly considered decision variables. However, ageing water distribution systems experience, with time, many problems such as structural failures, drop in carrying capacity and poor water quality, which, in the absence of any adequate rehabilitation programme, become more pronounced over the years. Similarly to design optimization, rehabilitation planning, whether by replacement, duplication, cleaning and relining of pipes, is often viewed as a least-cost optimization problem. Therefore, the terms “optimal design” and “optimal rehabilitation planning” of water distribution networks will be used interchangeably in this paper to describe the process of finding the best value for some goal associated with the model of a water distribution (or wastewater) system.

Recently, genetic algorithms (GA) have become the preferred water system design optimization technique for many researchers (Savic and Walters, 1997). This method uses full network model simulation to evaluate how good a design solution is and, therefore, may require substantial computing time when real networks are considered.

1.2. DETERMINISTIC PROBLEM

The classical optimal design/rehabilitation problem for a general water supply network aims to design a water distribution network while minimizing the cost and meeting the pressure requirements at nodes. The problem is solved if the solution satisfies two requirements: a) minimum cost; b) all nodal pressures exceed a required minimum. The mathematical formulation of the problem is as follows:

$$f(D_1, D_2, ..., D_N) = \sum_{i=1}^{N} c(D_i, L_i) \rightarrow \min \tag{1}$$

$$H_j \geq H_j^{\min}, j = 1, ..., M \tag{2}$$

$$D_i \in D(i = 1, ..., N_d) \tag{3}$$

where: – cost of pipe i with diameter Di (which is chosen from a discrete set of available diameters) and length Li, Hj – head at junction j, – minimum allowable head at node j, N - number of pipes in the system selected as potential rehabilitation candidates, Nd – number of decision variables, and M - number of junctions.

To calculate the state of the system for any given configuration and fixed demands one has to solve the non-linear system of equations. More details of the mathematical problem statement can be found in Savic and Walters (1997).

2. Stochastic Problem Formulation

The above deterministic approach assumes that all model input variables (e.g. demand, pipe friction characteristics, etc) are precisely known from observations or forward projections, which is not true for real-life systems. While it is possible to estimate present water demands reasonably well, the situation becomes much worse when future demands need to be predicted. Pipe roughness coefficients are usually estimated or derived from model development and calibration studies, and will change significantly with time – depending on pipe material and corrosion factors. Given the above, there is a clear need to consider uncertainty in input parameters and model output results when seeking the best design of water distribution systems.

Previous attempts to include demand uncertainty in the formulation of the network optimization problem by Lansey et al. (1989) and Xu and Goulter (1999) formulated the optimization problem with a single objective, accommodating the uncertainties as constraints. The problem is then solved using the Generalized Reduced Gradient (GRG2) technique (Lansey et al, 1989). Xu and Goulter (1999) used a probabilistic model in a network-design optimization for the first time. The uncertainties of the model simulation results were quantified through the analytical technique known as the First-Order Reliability Method (FORM). This technique requires repetitive calculations of first-order derivatives and inversion of matrices and, consequently, requires substantial computational effort - even for small networks. Furthermore, prior studies have shown that the GRG2 method may have a tendency to converge to a local minimum. The application of this method also requires that the decision variables (i.e. pipe diameters) be modeled as continuous variables, which does not reflect the reality of pipes being manufactured in a set of discrete-sized diameters. In order to overcome the above limitations, Kapelan et al. (2003) and Babayan et al. (2005) developed two new robust design methodologies, which make use of GAs. The former technique uses a sampling-based methodology to quantify the relevant uncertainties while the latter uses an analytical methodology for the same purpose.

The formulation of a robust design problem for both of the above uncertainty quantification techniques differs from the formulation of the deterministic problem (1)-(3) in the way the constraint of Eq. (2) is expressed. The minimum pressure constraint now becomes the target robustness constraint:

$$P\left(H_j \geq H_j^{\min}, j = 1,\dots,M\right) \geq P_{\min} \tag{4}$$

where: P – robustness, i.e. probability that nodal heads are above the minimums required and $P_{\min}$ – minimum required (i.e. target) level of robustness. If the problem is approached from the multiobjective point of view, the chance constraint of Eq. (4) is replaced by an objective to maximize P, i.e

$$P\left(H_j \geq H_j^{\min}, j = 1,\dots,M\right) \tag{5}$$

3. Sampling and Uncertainty Quantification

In the methodology presented here, the sampling technique is used to quantify the relevant uncertainties. Each time the two objectives (minimize cost; maximize robustness) are calculated, a total of N_s sets (i.e. samples) of random nodal demands are generated. The corresponding nodal heads are then obtained by running the hydraulic simulation software for each of the demand samples. The robustness P in (5) is estimated as the fraction (i.e. percentage) of total number of samples N_s for which the minimum head requirement condition is met simultaneously at all network nodes.

When calculating the value of objective functions, the conventional approach would be to use a Monte Carlo (MC) sampling technique with a large number of samples. In the approach presented in the paper, the Latin Hypercube (LH) technique (with much smaller number of samples) is used. By using the LH sampling technique values of stochastic input variables (nodal demands here) are generated in a random, yet constrained way. First, the range of each stochastic variable is divided into N_s non-overlapping, equal probability intervals. Then a single random value is selected from each interval. This process is repeated for all stochastic variables. Once the process is completed, the N_s values obtained for the first stochastic variable are paired in a random manner with N_s values obtained for the second stochastic variable and so on. The main advantage of the LH over the MC sampling technique is the better random sample stratification leading to more accurate estimation of the empirical, nodal head p.d.f. tails. However, LH sampling requires a larger computational effort to generate the same number of samples as MC. Fortunately, when the number of samples is small (e.g. less than 100) this difference is not significant.

4. Optimization Method

A modified Non-Dominated Sorting Genetic Algorithm, NSGAII (Deb et al. 2000) capable of performing efficient multi-objective search under uncertainty is presented. The GA is named the "robust NSGAII" or rNSGAII. The rNSGAII breeds solutions (i.e. chromosomes) which are robust enough to survive over multiple generations. This enables calculation of each chromosome's objective as the average of past objective values over that chromosome's age. As a consequence, even if a small number (e.g. 5-20) of LH samples is used for each objective evaluation, the objectives are effectively evaluated using larger number of samples (100-400 if a chromosome survived for, say, at least 20 generations). This way, significant computational savings can be achieved when compared to the full sampling approach where, typically, thousands of samples must be used. The following rNSGAII search procedure is used:

1. Create the initial GA population at random. Initialize the age of each chromosome to zero.

2. Evaluate the fitness of each chromosome by calculating the values of cost and robustness. Use a small number of Latin Hypercube samples.
3. Sort the chromosomes in the initial population using the fast non-dominating sorting algorithm and identify the non-dominated (i.e. optimal) Pareto front. Save this front.
4. Create the next generation population as follows:
    a. Increase the age of all chromosomes in the existing ("Parent") population by one and re-calculate the objective values for each chromosome by averaging the new and past objective values over chromosome's age.
    b. Create the "Children" population from the Parent population using the GA operators. Set the age of chromosomes in the Children population equal to zero. Calculate objective values for each chromosome in the population.
    c. Combine the Parent and Children populations into a single population. Use the fast non-dominated sorting algorithm and the crowding distance operator to form the next generation population. Identify the non-dominated Pareto front.
5. Increase the age by one and re-evaluate the objective values of all chromosomes in the previously identified non-dominated Pareto front (step 3). Combine this front with the Pareto front identified in the previous step (step c). Identify the new non-dominated Pareto front using the fast non-dominated sorting algorithm. Allow for chromosomes in the Pareto front identified in step c to dominate the chromosomes in the Pareto front identified in step 3 only if their chromosome age is equal to or above some pre-specified minimum age (MA).
6. Repeat steps 4-5 until some convergence criterion is met. Once the GA has converged, re-evaluate each solution on the non-dominated Pareto front using a large number of Monte Carlo samples (100,000 in the case study presented here).

The rNSGAII effectively exploits the fact that GA search process is stochastic with a population of solutions evaluated at each generation. It is a well known fact that GA searches (near) optimal solution by combining highly fit building blocks of population chromosomes (Goldberg 1989). As the search progresses, the population is likely to have more and more chromosomes containing highly fit building blocks. As a consequence, a relatively large number of indirect evaluations of these building blocks are likely to be found in the population even if a small number of samples are used to evaluate each chromosome's fitness.

5. Case Study

5.1. PROBLEM DESCRIPTION

The robust optimization methodology presented in this paper is tested on the problem of New York Tunnels (Schaake and Lai 1969). The objective of the problem was to identify the least cost network rehabilitation solution which satisfies minimum head requirements at all nodes for a set of fixed nodal demands. The only means of rehabilitation allowed is to duplicate existing pipes with new ones. A total of 16 solutions are possible for each pipe in the network (do/do not duplicate that pipe, 15 available diameters - range 91-518 cm). Even though the network is fairly small, the optimization problem is quite large (total number of possible network configurations is $16^{21}=1.9\times10^{24}$). A number of authors have solved it as a deterministic, single-objective problem, one of which is the solution by Murphy et al (1993), as given in Table 1.

The objective of the analysis is to identify the Pareto optimal front for the rehabilitation of the New York tunnels, i.e. to solve the stochastic optimization problem. To assess the sensitivity of the method, multiple rNSGAII runs are performed with different number of LH samples (N_s=5, 10 and 20), different required minimum ages of chromosomes (*MA*=5, 10, 20) and (five) different random seeds (i.e. different initial populations). The following set of GA operators and associated parameters were used in all runs: a population of 200 chromosomes, bit-tournament selection operator (selects two chromosomes at random and then keeps the one with higher fitness), a random uniform crossover operator with 0.70 crossover rate and a random-by-chromosome mutation operator (alter a single gene only) with 0.90 mutation rate. All rNSGAII runs were terminated after 500 generations and the Pareto optimal fronts found were re-evaluated using 100,000 MC samples.

Nodal demands are assumed to be the only uncertain variables following a Gaussian p.d.f. with the mean equal to the deterministic demand value specified in Murphy et al. (1993) and the standard deviation equal to 10% of the mean value (i.e. coefficient of variation C_v=0.10). This brings the total number of input model variables to N_v=19.

5.2. RESULTS AND DISCUSSION

A selection of Pareto optimal fronts obtained for uncertain demands are shown in Figure 1. The curve labeled “LH1000” represents the Pareto optimal front obtained using the standard NSGAII (Deb et al. 2000) with 1000 LH samples for each fitness evaluation at each stage of the GA (100,000,000 simulation runs during the optimization process). The three points/solutions labeled rccGA (robust chance-constrained GA) represent the solutions obtained using the robust, single-objective optimization approach (Kapelan et al. 2004). The following can be seen from Figure 1: (1) All Pareto optimal fronts obtained using small numbers of LH samples (LH5-LH20) are in very good agreement with the "full" sampling approach (LH1000); (2) The coverage and spread quality of the identified Pareto optimal fronts increases with the number of LH

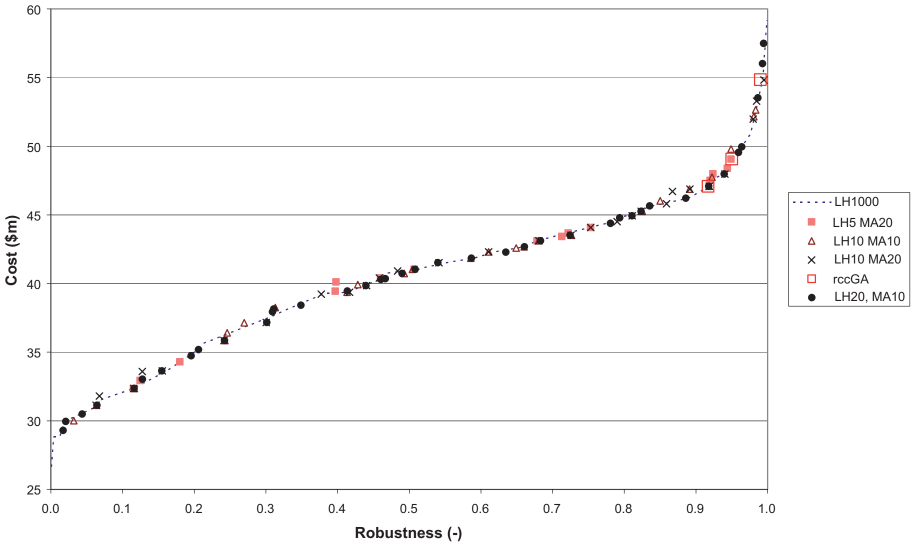

Figure 1 Pareto Optimal Fronts

samples used. While the Pareto optimal front obtained for N_s=5 LH samples is not very good in terms of both coverage (not uniform) and spread (neither of the front tails identified) of the solutions obtained, the Pareto front for N_s =10 and especially for N_s =20 have much better coverage and spread of solutions. This is no surprise since larger the number of samples the higher the resolution with which the solution robustness can be determined; (3) The robust methodology is not very successful in identifying solutions with extremely high robustness levels (e.g. 99.9% and above). This is a consequence of the small number of samples used here (5-20). However, it is likely that extremely high robustness solutions could be successfully identified if the number of samples is increased (e.g. to 50 or 100, still significantly less than thousands of samples!); (4) The three optimal solutions obtained using the single-objective approach are in excellent agreement with the corresponding Pareto optimal solutions; (5) The cost of rehabilitation solutions rises exponentially for the high robustness levels (approximately 0.90 and above).

6. Conclusions

An approach to dealing with input uncertainty while providing decision support for urban water systems is analyzed in this paper. The uncertain parameter considered in the robustness evaluation model is the nodal demand. The robust design problem is formulated as a stochastic, constrained optimization problem. A multiobjective optimization methodology is verified on a case study, for which, optimal robust solutions obtained are compared to well known deterministic solutions from the literature. The results clearly demonstrate that neglecting uncertainty in the design process may lead to serious under-design of water distribution networks.

TABLE 1 New York Tunnels Problem Solutions

Pipe No.	Deterministic Solution Murphy et al. (1993), D_i (cm)	Stochastic Solution (P_{min}=90%), D_i (cm)
1-13	-	-
14	-	-
15	305	457
16	213	244
17	244	274
18	213	213
19	183	183
20	-	-
21	183	213
Cost ($m)	38.80	47.08
Robustness P*)	35.3%	91.7%

*) Estimated using 100,000 MC samples

The methodology proposed is of a general type, in that any p.d.f can be used to model uncertain demands and other parameters (such as pipe roughnesses). Unlike in the First Order Reliability Method (Xu and Goulter, 1999), the methodology shown here does not require existence and calculation of the first-order derivatives of nodal heads ($\partial H_i/\partial Q_j$). This is an important advantage, especially in the case of complex networks with various control devices where such derivatives may be very difficult or, in some cases, impossible to obtain.

The robust design methodology presented here seems to be capable of identifying Pareto optimal fronts for uncertain input variables while achieving significant computational savings when compared to the full sampling technique. The computational savings obtained are in the range of *two orders of magnitude.* This is important because in a single run the whole Pareto front is obtained which allows for the responsibility of assigning relative values of the objectives to remain with the decision maker. The sampling method works only with population based search algorithms because it actually takes advantage of these search techniques and reduced MC samples. The sampling method can easily handle the hydraulic model non-linearity.

Acknowledgement

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AGEING AND RENEWAL OF URBAN WATER INFRASTRUCTURE

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Abstract. A framework for the rehabilitation management of urban water infrastructure is introduced, which distinguishes between a long-term strategic approach on the network level, and a detailed approach for setting short term rehabilitation priorities on the single pipe level. Based on a detailed condition analysis, life time expectancies for water infrastructure pipe types are defined, future rehabilitation needs are calculated, and alternative strategies are systematically compared. Then, priorities for rehabilitation are defined with a set of decision criteria within the framework of the given budget of a calculated strategy by a formalised interactive elimination procedure. Both approaches found their way into the CARE-W and CARE-S decision support systems, which have been developed in research projects under the 5th framework programme of the EC.

Keywords: water networks; rehabilitation; strategy; priority setting

1. Introduction

After decades of urban growth and development associated with the installation and extension of urban water systems and their infrastructure networks, one is approaching now a phase of deterioration of these networks with the consequent needs of rehabilitation; or, in other words: it's the dawn of the replacement era (AWWA, 2001). Major endeavours have been undertaken to investigate the mechanisms of deteriorating water systems and to find formulas for the

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management of their rehabilitation (Herz, 2002). However, ageing processes of industrial goods and systems are not only of interest in our present. They have been subject to observations and investigations, by engineers, economists, and scientists, already in the past, for instance in times of the European industrialization. From those times, we find the characterisation of two types of wear and tear: the physical, and the moral deterioration. In his main œuvre "The Capital" in 1876, (Marx, Karl, 1876) Karl Marx illustrates vividly these two terms:

"The material wear and tear of a machine is of two kinds. The one arises from use, as coins wear out by circulating, the other from non-use, as a sword rusts when left in its scabbard. The latter kind is due to the elements. The former is more or less directly proportional, the latter to a certain extent inversely proportional, to the use of the machine.

But in addition to the material wear and tear, a machine also undergoes what we may call a moral depreciation. It loses exchange-value, either by machines of the same sort being produced cheaper than it, or by better machines entering into competition with it. In both cases, be the machine ever so young and full of life, its value is no longer determined by the labour actually materialised in it, but by the labour-time requisite to reproduce either it or the better machine. It has, therefore, lost value more or less. The shorter the period taken to reproduce its total value, the less is the danger of moral depreciation; and the longer the working-day, the shorter is that period. "

Like Marx' industrial machine the elements of urban water infrastructure are exposed to the processes of physical and moral depreciation. As an example of the physical deterioration process of a pipeline we could consider the corrosion of metallic pipes. The moral deterioration of pipelines, on the other hand, could be observed in the case when the capacity of a distribution pipe no longer corresponds to the changing demand; or the installation quality of a sewer no longer copes with changing environmental standards. Both phenomena – physical, as well as moral depreciation – play their role in the determination of the end of the service life of water infrastructure elements.

Consequently, the rehabilitation management of deteriorating urban water infrastructure systems requires a critical look on two major issues: How much will we have to spend on rehabilitation in future years in order to keep a sustainable level of service – i.e.: how many pipes will come to the end of their service life? Then, the second question will be: Which parts of the network shall be rehabilitated first in order to spend the budget on the most cost-efficient parts, and to prevent the highest risks? Obviously, these two questions are closely linked to each other. Nevertheless, different approaches seem to be appropriate in the analysis: On the network level for the development of a long-term strategy, and on the pipe level for setting priorities. Unlike for the design of a new network, the rehabilitation of an existing network can not be solved by an optimisation function. This task will always be to looking for a compromise.

Strategic rehabilitation aims at keeping or improving the level of the network performance in the long-term. The development of a strategy is requested for achieving these objectives at minimum costs. This must be approved in advance by forecast calculation. Where in the network, and how this money will be invested, is a question of priority setting, finally.

Rehabilitation strategies are developed on the network level. Hereby, the evaluation of individual elements of the system is of secondary importance. The objective is to find a – financial - response to mid- and long-term tendencies in the deterioration process of the infrastructure. However, priority setting for short-term rehabilitation investment plans is oriented towards the condition and the costs of the individual project, and is based on a set of decision criteria. Finally, performance indicators are the tools for controlling the success of the investments in the long-term, and the implementation of a long-term strategy into short-term rehabilitation priorities.

2. Condition Analysis and Evaluation

The continuous deterioration process of pipelines with age is obvious, and can be proved by statistical failure analysis. The older a pipe the more likely its failure, and the more frequent a pipe has been repaired before, the more likely it is that the pipe will fail again (Eisenbeis, 1994), but in general, the individual pipes do not age homogeneously. Therefore, the evaluation of the network condition must be based on the detailed analysis of the assets and their failure histories. Data interpretation is most beneficial, if failure records are clearly assigned to asset data. The first objective here is the definition of types or pipes, which show a homogeneous ageing behaviour. In the long-term forecast of rehabilitation needs, it is sufficient to make this distinction of pipe types (Kropp and Baur, 2004).

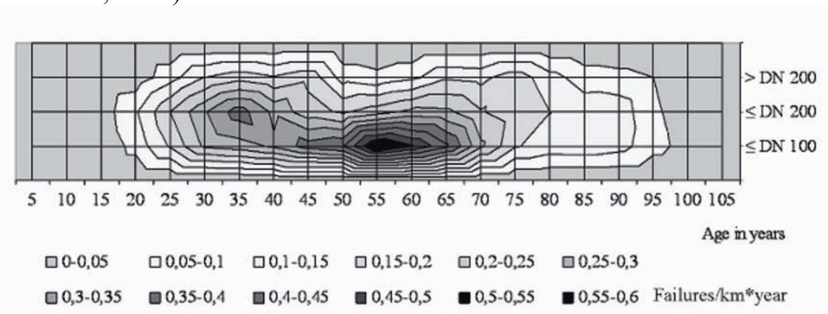

Figure 1 Failure rates on cast iron pipes by age and groups of diameter

The service life of a pipe type can be defined by a probability density distribution with expectancy value and standard deviation, which can be derived from failure records by age (Figure 1) or from the rehabilitation history (Figure 2). In the case of more recently installed pipe types with a shorter failure history, such as PE-, or well protected steel and ductile iron pipes, there is usually no alternative to define the service life but by experts' guesses.

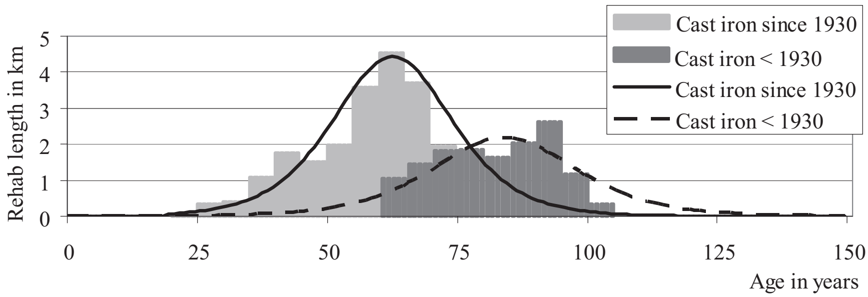

Figure 2 Determination of service life for pipe types (example)

From the probability density distribution of the service lives, the survival functions are mathematically derived (Figure 3). Of course, the rehabilitation of a pipe is not only condition based. Beside different "ageing speeds" of individual pipes, the standard deviation covers other reasons for the rehabilitation of a pipe as well: For example rehabilitation for hydraulic upgrades, or pipe replacement in the course of coordinated works on parallel infrastructure networks.

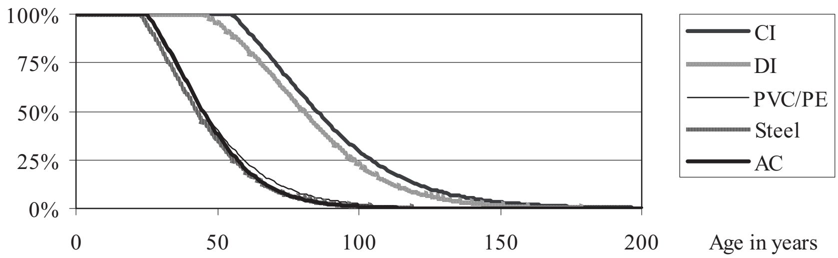

Figure 3 Survival functions for different pipe types (example: materials)

3. Forecast and Strategy

Forecast rehabilitation needs are calculated from the age distribution of the existing inventory with the life time expectancies of the different pipe types. The residual service life of a particular pipe is calculated from its age and the total service life expectancy of the pipe type. Within a cohort-survival model, year by year the future rehabilitation needs are calculated then (Figure 4).

The network operating company should react on the forecast needs with an appropriate strategy. By the KANEW-approach (Figure 5), which found its way into the German standards DVGW W 401 and G 401 (Guidelines for the rehabilitation of water and gas networks), and into the CARE-W project (Herz, 2002), rehabilitation programmes and their consequences are simulated. Various input parameters on duration and extend of the strategy, unit costs, and discount rates, are used for the calculation of selected technical and economic performance indicators. Thus, alternative strategies can be compared systematically.

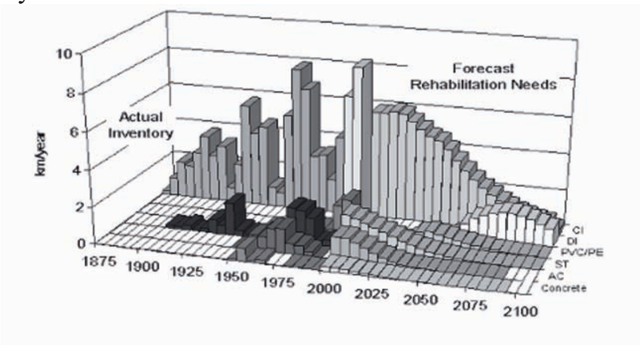

Figure 4 Inventory by pipe type and installation period, and forecast rehabilitation needs (BAUR+KROPP 2005)

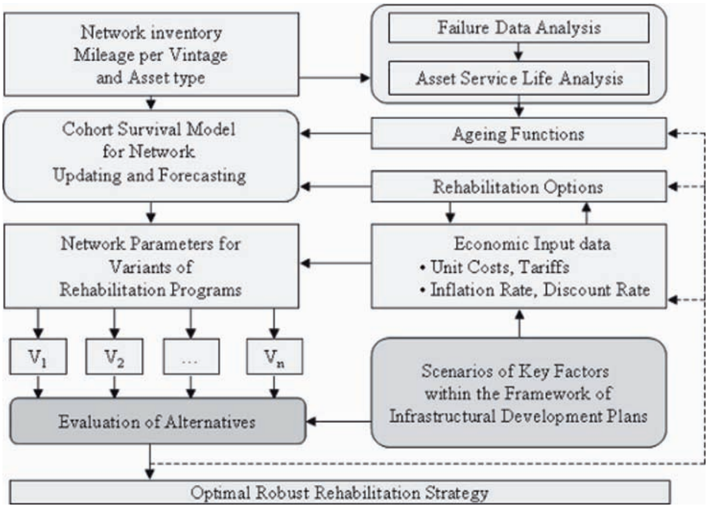

Figure 5 KANEW - Framework

In the short term, investments into network rehabilitation do not pay off, due to the relative high investment costs that have to be paid immediately, in the beginning of the period under consideration, but the benefits accumulate only in the long run in terms of avoided maintenance, repair, and leakage costs on the old pipe. Thus, investment programmes are set up for manageable periods of 5 to 10 years, whereas the effects are forecast and considered for a time horizon of 40 to 50 years. Figure 6 illustrates for two alternative strategies the calculated rehabilitation needs, and compares them with the rehabilitation rates in the past. Both strategies are defined for a 10 years planning period, and effects are calculated until the year 2050. Strategy 1 orients towards a replacement rate of 0.8% of the network length, corresponding to the rehabilitation activities in the past. For strategy 2, an extreme scenario is simulated, assuming a do-nothing option for any capital maintenance in the network, thus only pipe bursts are repaired. Below the rehabilitation rates, the calculated cost balances for both strategies are given, including the discounted annual investment costs, and the monetary benefits in terms of the discounted and accumulated costs for repair and losses, which are avoided by replacing the old pipes. As expected, during the first ten years the do-nothing strategy is the preferential option. In contrast, Strategy 1 shows a clear positive trend of the cost balance from the beginning, whereas in the case of doing nothing, rehabilitation needs are just postponed into the future. In addition, the example shows that investments pay off after a period of 30-35 years, which would be already far beyond typical planning horizons.

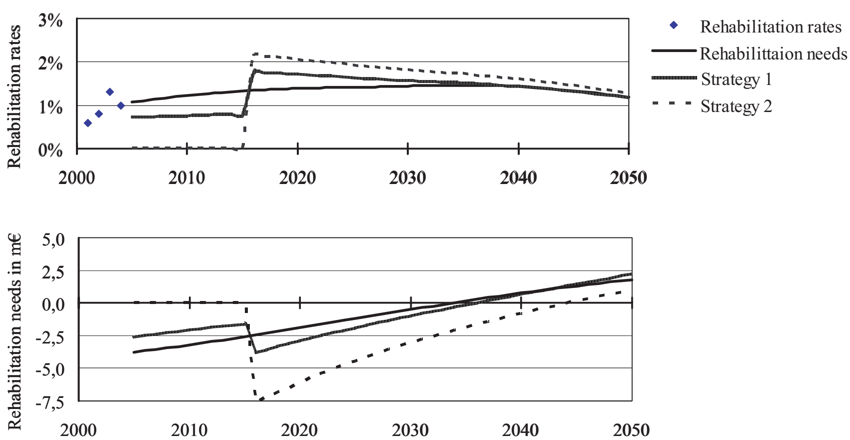

Figure 6 Rehabilitation strategies: Rehabilitation activity in the past, calculated needs and strategy forecasts (top), and corresponding cost balances (below)

In the long-term, a rehabilitation strategy could be oriented towards the development of the average service life reserve. This technical asset value can be defined as follows:

$$Technical\ asset\ value = \frac{Residual\ service\ life}{Age + Residual\ service\ life}$$

with

- age: average age of the infrastructure network elements
- residual service life: average expectancy value for the residual service life of the infrastructure network elements

In figure 7, the development of average service life reserve, the average age, and the average residual service life of the infrastructure network elements are illustrated. The technical asset value is a relative measure that relates the average residual service life to the average total service life expectancy of the pipes. For the benefit of a sustainable network development, 0.5 is the target technical asset value (TAV), and a decreasing TAV should be avoided.

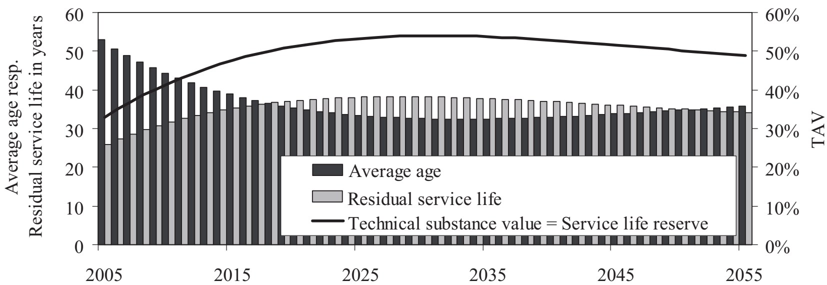

Figure 7 Average age, Residual service life, and Technical asset value (TAV)

4. Setting Rehabilitation Priorities

Long-term strategies on the one hand are developed on the network level. Rehabilitation priorities, on the other hand, are defined on the single pipe level, using a set of decision criteria. The condition evaluation of the single pipes is based on a detailed failure data analysis and hydraulic modelling. In general, the most important criterion for the rehabilitation decision is the accumulated number of pipe failures in the past; that is the reason for recording failure information. Here, the age of the pipes is of minor importance, but the combination of age and pipe type permits an estimate of the residual service life of the pipe. However, failure frequency and leakage rate are not the overall-dominating argument for rehabilitation; the decision depends also on the potential consequences of failures (Baur et al., 2005). For instance, a pipe burst under a trunk road, with a number of public transport lines and large shopping areas, necessarily leads to higher direct and indirect failure costs than the leak of a pipe in a side street. Here, the simplified failure costs are all potential consequences of the failure of that particular pipe. However, in the first case, the failure-risk is – for an equal failure probability – much higher, if we define the failure risk as the product of failure probability and the direct plus indirect costs in case of a failure.

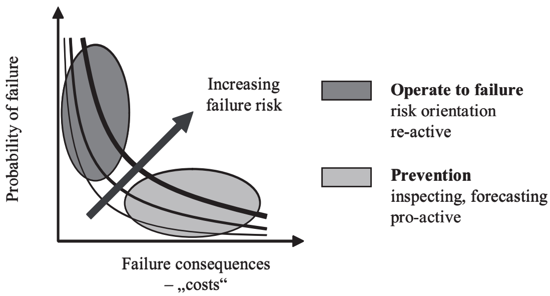

Figure 8 Failure risk and Rehabilitation management strategies (simplified)

In figure 8, the hyperbolic curves are iso-lines of equal failure risks with an increasing tendency. For rehabilitation activity, those lead – simplified after (Buckland, 2000) – to two fields of action: Are the consequences of a failure relatively small (the side road), then for a longer period re-action may be appropriate, and continuous repair may be an adequate solution. The higher the – direct & indirect – costs in case of a failure are, the more appropriate pro-active rehabilitation would be. This might be the case, for example, in the case of large feeder mains, or large diameter distribution pipes in city centres. Statistical models, like the Proportional hazard model applied in CARE-W (Herz, 2002), are suitable for the calculation of future failure probabilities. Before action on the single pipe level, nevertheless, the uncertainties of such statistical models should be taken into account.

Consequently, for setting rehabilitation priorities, the failure rate must not necessarily have the same weight for each single pipe. It depends, for example, on the location and the corresponding land use patterns as well. So, the value of one criterion is relative, for it depends on the values of other criteria as well; and subsequently, it is not possible to normalise it by a particular utility function, and let these values substitute the values of other criteria (Vincke, 1992): for example the consequences of a failure on direct costs (repair) are not substitutable versus the indirect costs of the serviceability of a public building nearby. Necessarily, the definition of rehabilitation priorities will always be a compromise rather than finding an optimum engineering solution, as we know it from the approaches of new design of infrastructure. Rehabilitation criteria follow a trade-off rule, rather than substitution logic.

The selection of pipes, ie the definition of priorities for their rehabilitation, is a balancing process. There might be case A of a pipe with a relatively high failure rate that could be accepted even in future, whereas pipe B would be unacceptable despite of a lower failure rate but even more serious potential interruptions of public transport lines. Or, in the case of planning the rehabilitation of a sewer network, trade-offs have to be balanced between high priority structural defects, and the network upgrade due to hydraulic bottlenecks, respectively unacceptable stresses on the environment. In any case, this problem will definitely not be solved by an optimisation approach, but in a step-by-step approach of finding the most appropriate rehabilitation plan, and thus the final result, or action plan, will be a robust compromise.

The interactive elimination procedure with effect control has been chosen within the CARE-S project for setting priorities in sewer network rehabilitation (Baur et al., 2005). This approach can basically be characterised as a feasibility study with effect control for elimination settings. Step-by-step candidates are eliminated from the total set, until a final priority list is found. Hereby the elimination process is controlled by the observation of consequences of the threshold setting on other criteria, on tables, graphically, and on the map. Its direct connection to and interaction with a GIS is one of the most important strengths of the procedure. In addition, it allows the consequent use of information and criteria on their original scale, be it for instance an ordinal, or a nominal one, without needs for transforming criteria values on a uniform scale.

Economic criteria are not neglected in the present approach. However, they are not used for the calculation of a monetary optimum of rehabilitation in the traditional sense (Herz, 1999). Direct costs are balanced against the benefits of rehabilitation that cannot be expressed in monetary terms. Thus, the objective of the decision support methodology is to finding a common sense, or acceptable compromise, rather than solving an optimisation calculation with multiple variables.

5. Summary

The presented framework for rehabilitation management of infrastructure networks is characterised by an integrated two stage concept:

1. Development of long-term strategic rehabilitation plans on the network level. This decision belongs to the responsibility of the upper management, and will play a more and more important role in the future due to the increase of regulation and control needs in the water industry sector, if for

instance future tariffs and investment plans must be negotiated with the authorities.

2. Setting rehabilitation priorities. Here, the benchmarks of long-term strategies must be translated into action, which is a task of the middle management, and of diurnal relevance. Both decisions are evaluated against each other on the basis of selected performance indicators.

A framework is introduced into rehabilitation management of urban water infrastructure, for both urban water supply and drainage networks, which distinguishes between a long-term strategic approach on the network level, and a detailed approach for setting short term rehabilitation priorities on the level of single pipes.

An optimisation of rehabilitation in the pure mathematical sense is neither possible for the strategy development, nor for the priority setting. Both piles of the introduced decision support framework are conceptually based on a detailed asset and condition analysis, linked by an integrated performance indication. The philosophy behind is the development of "robust" solutions, which consider beside the technical optimum always the politically feasible option.

The concept found its way not only into the CARE-W and CARE-S projects, both funded under the 5th framework programme of the European commission (Herz, 2002, Baur et al. 2005). Due to the strength in the practical relevance of its solutions, the philosophy has been applied also in a number of studies for European and Northern American utilities (see KANEW web pages).

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BENCHMARKING OF WATER SUPPLY SYSTEMS - WATER LOSSES ASSESSMENT

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Abstract. Modern methods of benchmarking are starting to be use for objective evaluation of water supply level, these methods provide relative comparison of attained results of water companies. Possibilities for improvement of companies create by comparison of selected indicators, such way we can define situation of company considering other similar companies. Selection of figure of merits is the most important for benchmarking method to give desired results by comparison of them. Important indicators of evaluation of water supply are not only financial indicators, but technical too, technical indicators characterise technical condition of water pipelines, fault liability and with these related water losses. Water losses are significant factor, which affects inefficient exploitation of quality water sources. Management of water company needs to obtain information about selected indicators to can apply benchmarking methods. For that purpose benchmarking centres are starting to institute in the world. In this report will be presented new approach of evaluation of water losses indicators from point of view operator of water supply. There will be described benchmarking method which can be use for evaluation of water supply systems oriented for water losses. In this article will be presented results of evaluation of water supply systems in Slovakia.

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Keywords: water supply; water losses; water losses indicators; non revenue water; benchmarking

1. Introduction

Modern methods of benchmarking are starting to be use for objective evaluation of water supply level, these methods provide relative comparison of attained results of water companies. Possibilities for improvement of companies create by comparison of selected indicators, such way we can define situation of company considering other similar companies.

Selection of figure of merits is the most important for benchmarking method to give desired results by comparison of them. Important indicators of evaluation of water supply are not only financial indicators, but technical too, technical indicators characterise technical condition of water pipelines, fault liability and with these related water losses.

Water losses are significant factor, which affects inefficient exploitation of quality water sources.

Management of water company needs to obtain information about selected indicators to can apply benchmarking methods. For that purpose benchmarking centres are starting to institute in the world.

In this report will be presented new approach of evaluation of water losses indicators from point of view operator of water supply.

2. Method of Benchmarking

Benchmarking as important tool of management was first time applied in company XEROX in 1979. From this time method of benchmarking started to apply in different regions and in different levels. There are several definitions of this method:

- „Benchmarking is continuous and systematic comparison of own (self) efficiency in productivity, quality and production process with companies and organisation which have (peak power) high production."
- „Benchmarking is application of systematic methods for comparison themselves with other and finding better ways how to make this work."
- „Benchmarking is monitoring other of purpose to learn from them."

Main goal of benchmarking is to build on successful experience of other instead inventing of wheel again. This idea is simple: the most productive way for implementation of change is to learn from positive experiences of other companies. Realisation of benchmarking with the best companies in similar type of activities can help to find way of achievement of success to organisation. Benchmarking is kind of management to accent systematic improvement.

„Learning organisation“ try to keep up contact with up-to-date and the best practices in the field by application of benchmarking instead of dependence on out-of-date ideas. Benchmarking is always practised to implementation of improvement. Analyse can be focused on products, processes and/or results. Organisation obtains information for improvement and development what can lead to improvement of efficiency. Benchmarking is not only process of creation, classification and comparison data gathered but it is dynamic process of information exchange to be effective tool (instrument) of change to be better.

Slovak benchmarking information centre (SBIC) like national centre intra-Europe and global network of benchmarking centres was instituted at Ministry of Economy of the Slovak Republic in 1999 in Slovakia.

Main plan of SBIC (www.sbic.sk) is to spread information about benchmarking – important tool of management, to achieve fast increase of competitiveness especially industrial plants.

3. Benchmarking of Water Companies

Acquirement of comparative information and their application in benchmarking became important managing tool for managers in water companies and plants too. First provider of benchmarking for water companies of all the world is IBNET - Water and Sanitation International Benchmarking Network which mediates opportunity for sharing of regional, national and international information. (www.ib-net.org.) It is dynamic database what is continual filling up.

World bank under the name „Benchmarking Start – Up Kit“ started with this initiative. On October 2003 Wrc plc (Water research centre, UK) obtained contract for control and development of this initiative specified as IBNET. IBNET provides possibility to create trustworthy global benchmarking network for water companies in developed and developing countries. IBNET will be mediate fast entrance to data in water sector by application presentation of base indicators oriented to web sites of „geographic points“.

IBNET helps to share especially international information to support of local benchmarking activities. This tendency has following reasons:

- it is hard to come to an agreement on universal indicators and their detailed definition
- availability of trustworthy data can be limited
- comparison between countries can be effected by different conditions of operations

Because of this was designed central monitoring system – each owner of water distribution system will build up its own monitoring capacities and his data will be made public by internet on the base of voluntaries. If these information are from users in adequate number, there will be added reference international data to each of the user. IBNET was developed for support of this concept what was described above. IBNET contains:

- main indicators, by means of these indicators operators can build their own measuring and monitoring system
- complete list of these indicators with their definitions
- representation of data – computation
- way to sharing of information

Main benchmarking indicators and their units are still exposed to extensive discussion to obtain minimisation of regional and local influences, which can distort their cancellation value. Because of this it is recommended to express water consumption not only as litres/inhabitant/day but in litres/household/day too because number of households is more accurately entered.

3.1. BENCHMARKING REALISED AT OPERATORS OF WATER INFRASTRUCTURE IN SLOVAKIA

On the Department of Sanitary Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava within the scope of solution of grant research work we are making benchmarking of technical figure of merits of water companies. After analyse of availability, representatives and authenticity of base data, technical indicators of water supply and water losses were selected at first analysis stage of solution for comparison. Indicators applied in IBNET could not use for their unavailability.

Applied method of benchmarking make possible to find out momentary state of each water companies compared with others at home and foreign market, this method leads to obtain of new information stimulus and motivate to improve of present stage. Results will be given anonymously, each company has allotted serial number.

At second analyses stage of task which is being smaller operation units like water supply systems of cities and villages in different size categories considering water losses will be submitted to benchmarking. Goal of this task is comparison of water companies with foreign companies. Task of this pilot project is incorporation of Slovakia to world-wide global partnership of network IBNET.

3.1.1. *Applied Method*

For benchmarking it is usually used applied anonym list of questions for collection of data. Collection of data for comparison selected indicators of water losses in Czech Republic was realised the same way, which organised SOVAK in 2002. In our condition it was not possible to obtain complete background and we had to use database of main indications of water companies, which are published at annual reports. Data during years 1999-2003 were analysed.

Indicators of water losses

International organisation IWA published new approach to evaluation of water losses and in 1996 assigned Task Force to make transparent existing techniques for international comparison of water losses in water supply systems.

Following indicators are recommended to use for evaluation of water losses:

1. Unit leakage of non-revenue water:
   - Volume of non-revenue water / total length of pipes (m^3/km/year; l/km/day)
   - Volume of non-revenue water/number of consumer lines (l/service connection/day)
2. Infrastructure Leakage Index ILI
   - Volume of real water losses / volume of theoretically necessary water losses (non-dimensional number)

4. Results

Volume of non revenue water, showed by water companies is more reliable indication as showed water losses and so indicators determined with volume of non revenue water were selected for comparison. Index ILI was checked the same way.

Computed indicators for 6 water companies in Slovakia during year 2002 were in the following range:

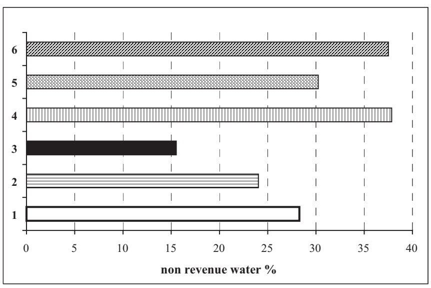
- unit leakage per km 3 600 – 8 000 m^3/km/year
- unit leakage per consumer line connection/day 260 – 700 l/service
- non-dimensional index ILI 4,5 – 12

Suitable technical condition means water distribution systems with unit leakage up to 4500 m^3/km/year.

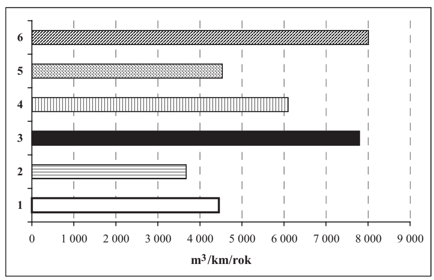
From evaluation of work group of IWA for water losses Infrastructure Leakage Index ILI was at intervals 0,8 – 11 for 27 water companies (of the world). If ILI >1,0, it is assumption to intensify effective control of water losses or to speed up repair.

In the figure 1a-d are showed data of selected indicators of water losses per year 2002 for water companies marked by numbers 1-6. Water companies sequence and sign are the same in the chart.

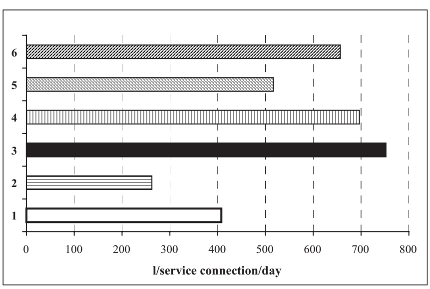
a) Values of non revenue water of water losses



b) Values of indicator m^3 km/year of water



c) Values of indicator l/serv./day of water losses



d) Values of indicator ILI of water losses

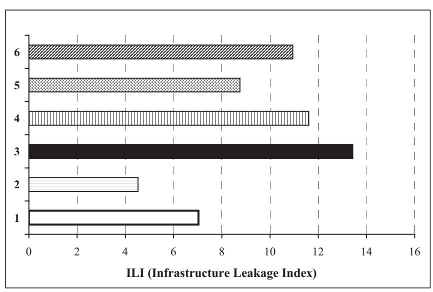


Figure 1 Selected indicators of water losses for water companies marked by numbers 1-6 (2002)

By now data from two selected water companies were prepared in more detailed. Data were prepared for various water supply systems, that were typed to 6 categories according to supplied inhabitants. Averaged values of indicators of water losses for created quantitative categories are presented in Table 1.

TABLE 1 Average values of indicators of water losses in dependence on number of supplied inhabitants.

Indicators	Unit	to 1000 supplied inhab.	to 2000 supplied inhab	to 5000 supplied inhab.	to 10.000 supplied inhab.	to 50.000 supplied inhab.	up 50.000 supplied inhab
non-revenue water	%	32,3	31,8	30,9	22,5	27,2	24
unit leakage per km	m^3/km/year	2136	2382	2948	3405	4790	4720
unit leakage per service connection	l/ser.conn./day	172,3	183,3	204	216,3	365,4	402,9
ILI	-	3,1	3,5	4,1	4,4	6,6	7,2
recovery of pipeline	m^3/m	6,6	7,5	9,5	15,1	17,6	19,7

5. Summary

Objective view about condition of water supply make only indicators for individual water supply systems (local water distribution or group water supply), e.g. where index ILI exceeds value 40. This will be achieved after evaluation of water supply systems. Benchmarking give possibilities to management of company to compare more selected indicators with international indicators at the same time and so to identify field which need greater care. Demonstration of benchmarking results of water losses in selected water companies will be presented on the Conference.

Acknowledgement

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WATER SUPPLY OF BUCHAREST - PAST, PRESENT, FUTURE: A STUDY CASE

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Abstract. The history of water supply of Bucharest is presented starting with the first drinking water systems with faucets till the actual situation when the water supply in Bucharest is provided by the company "Apa Nova", controlled by the French Group Veolia Water and by the Municipality Council. The main conditions of the Concession Contract, evolution of few key indicators/levels of services and technical/operational results are presented. The average water consumption per inhabitant, as well as specific consumption in industry is higher than in other countries and this due and to exaggerated losses along the delivery and distribution networks, to waste and to inefficient technologies that were used. The main measures taken in order to improve the situation of the water supply system of Bucharest:

1. investments programs;
2. organizational measures for:
   - reduction of the water losses in WTP
   - reduce/minimize water demand for supply systems through leakage detection and remediation
   - implementation of water reuse

are described.

Keywords: history of water supply of Bucharest; evolution of few key indicators/levels of services; technical/operational results; average water consumption per inhabitant; investments programs; organizational measures

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1. History of the Water Supply of Bucharest

The first documental mention of the city of Bucharest is from 1459; after 1862 became the capital of Moldavia and Valaquia Principalities and after 1881 the capital of the Romania Kingdom.

The first drinking water systems with faucets were dated on the Alexandru Ipsilanti time (were mentioned on a document from 1st of October 1779) and the first canalization system from springs, made from burned yellow ground, was from 1786.

In 1847 was inaugurated the first mechanical installation, named "The Fountains Establishment" and at 2nd of September 1888 was started the

In the period 1882-1888, it was created the first compartment (10.000 m^3) of a reservoir at Cotroceni. The water, brought through the Arcuda-Bucharest aqueduct, entered into a room of 2,70x2,30m, then got into a cast iron pipe of 750 mm, being distributed then in the compartments of the reservoir.

On 21 of July 1923, the Municipality of Buchrest decided to unite all the communal services under a direct administration in a "regia" called "Uzinele Comunale Bucuresti" (UCB- Bucharest Communal Works, approved by a law called "Administrarea si Exploatarea Uzinelor Comunale Bucuresti" (Administration and Operation of the Bucharest Communal Works). The first UCB achievements were:

- Bragadiru III collector (232 wells, H=616 mm, length of the front 5.5 km, between Sabar and Arges), completed in 1926
- a lot of modernizing works at Arcuda: between the clarification basins and filters were carried out 7 demagnification and 26 ante filters (1926-1927)
- works for slow filters concreting at Arcuda (1935) and it went for water chlorinating (1938)
- 44.6 km of network were replaced (1923-1943)
- many deep wells were drilled in order to increase drinking water flow.

In 1939, started the works at the Crivina barrage and at the Arges-Rosu channel (Q=8 m^3/sec, length 20km). The works were stopped during the war and began only in 1947.

In the period 1951-1953, there were executed works in order to increase the water production at the Arcuda Treatment Plant, by rising the filtering speed. The fast filters were created by the experimental transformation of the pre-filters; the water production grew from 60-70.000 m^3/day to 140-150.000 m^3/day. Development of the Arcuda Treatment Plant was done from 1954 till1959, by creating a coagulant station, decanting basins made of concrete, fast filters, a chlorination station, a thermal central, aqueducts and a transformation station.

In 1970 were finished the works at the second water treatment plant of the Bucharest, Rosu – Stage I.

The production of the Arcuda plant grew from 485.000 m^3 /day to 745.000 m^3/day in 1981.

On 10 December 1990, the General Water Company of Bucharest (RGAB) was created by Decision no. 1198 of the Municipality of Bucharest. On 28 January 1998, the agreement regarding the advising on the privatization, corporatization and restructuring of the RGAB was assigned. The International Finance Corporation (IFC) became the main adviser on the corporatization, restructuring and privatization of the RGAB.

2. The Present of the Water Supply of Bucharest

On 20 March 2000, Veolia Water won the tender to privatize the Bucharest municipal water services.

The water supply in Bucharest is provided by the company "Apa Nova", controlled by the French group Veolia Water and by the Municipality Council. It has obtained such competence after a public tender organized by Bucharest City Council, the Romanian Government with assistance from the World Bank (International Finance Corporation).

Apa Nova develops the activity according to the Concession Contract sign on 20 of March 2000. The conditions of the Contract are:

1. Bucharest Municipality remains the owner of the public goods for the water supply and sewerage (treatment stations, pumping stations, distribution red, tanks,…)
2. Apa Nova received together with the Service Contract, the goods administration right and the goods exploitation right:
3. Apa Nova has the responsibility of the administration and rehabilitation.
4. The contract is a “results contract” that let to the Concessionaire the liberty to choose the means to fulfill it.
5. Apa Nova is responsible to ensure the necessary investments in order to obtain the “Services Levels” mentioned in the contract.
6. The control of the fulfillment and of the maintenance of the Services Levels is ensure by ARBAC (The Regulatory Agency for the Water and Sewerage Services in Bucharest)

7. The evolution of the tariffs is under the responsibility of different factors from national and local level but are under an International Experts Commission
8. The Contract is sign for 25 years.

2.1. POTABLE WATER SUPPLY OF BUCHAREST TODAY

The potable water supply of Bucharest City is mainly ensured by two treatment stations from Rosu and Arcuda. The water is then pumped successively at the various pressure levels, through the pumping, re-pumping and hydro-pumping stations, being then distributed to the consumers through the distribution network.

2.1.1. *Arcuda plant*

Over 100 years old, having a potable water production capacity of 745,000 m^3/day, the plant is supplied with raw water from Dambovita River by water dam located at a distance of 17 km upstream. Through a channel, the raw water enters a pre-settler and a group of natural settlers with a length of 2 km. The water is made potable through the following steps:

- coagulation and flocculation with aluminum sulfate, allowing the elimination of colloids, their destabilization and grouping into floccons; later, the separations of suspended matters is performed by settling;
- the sand filtration allows the elimination of the suspended matters which are not settled;
- the injection of chlorine gas for elimination of pathogen microorganisms, bacteria and parasites.

2.1.2. *Rosu Plant*

The Rosu Water Treatment Plant is supplied with raw water from Arges River. through a water dam located 12 km upstream, transported through an aqueduct. The water which reaches the plant goes by pumping into the treatment flow:

- correction of pH by injection of sulfuric acid or lime suspension;
- coagulation on flocculation with aluminum sulfate and polyelectrolyte;
- disinfection with chlorine gas.

The total production capacity of the plant is of 520.000 m^3/day.

2.1.3. *Underground fronts*

The three underground fronts group over 600 drilling wells, with a production capacity of about 100.000 m^3/day. The water from these wells is directed straight into the potable water aqueducts. As this water is an under average water quality and constantly degrading, the production of the wells is much reduced, in order to distribute potable water of a perfectly controlled quality.

2.1.4. *Thanks and pumping*

An aqueduct network transports the potable water to the 20 storage tanks. The storage tanks are generally doubled at each pumping station, allowing the continuous supply of the customers connected to the low pressure network and the re-pumping stations. The buildings of at least 4 floors, as well as the heating points, are supplied with potable water by high pressure stations (re-pumping and booster stations). At the end of 2004, in order to ensure water pressure for the consumers, Apa Nova operates:

- 38 re-pumping stations;
- 194 booster stations.

2.1.5. *Potable Water network and connections*

The water supply system of Bucharest has:

- 2372 km of main pipes and service pipes;
- around 670 km of pipelines related to more than 89.000 connections

These pipes are made of steel, premo (armed vibrated concrete), cast iron, concrete) or lead. Now only PEHD and ductile cast iron are used for the modernization and replacement programs (according to areas and diameters). Within these works, Apa Nova replaces and equips the connections with valves or water taps placed on public domain, for facilitating the interventions. A similar action is also carried out for hydrants.

2.2. LEVELS OF SERVICES

The Concession Contract, sign between Apa Nova and the Municipality Bucharest Council, doesn't provide investment amounts but sets out the service targets to be achieved by the Apa Nova, the method of measurement, the monitoring procedures, the compliance requirements and allowable exclusions (if applicable), and the remedial actions to be taken off.

The Contract includes targets for the following service indicators in relation with potable water supply system operation:

1. Potable Water Quality
2. Pressure at the connection
3. Continuity of Service
4. Coverage
5. Time between notification of burst/leak and reinstatement of service
6. Time to provide alternative supply of potable water
7. Water billed and metered as a percentage of water produced

2.3. THE ACTUAL PERFORMANCES

Measures were taken in order to reduce the losses in the water supply system of Bucharest. Among these can be mentioned:

1. investments programs;
2. organizational measures for:

- reduction of the water losses in WTP
- reduce/minimize water demand for supply systems through leakage detection and remediation
- implementation of water reuse.

2.3.1. *Investments programs*

Details about the main actions to improve the performances of the water supply system of Bucharest are presented in the next table.

TABLE 1 Listing of the main actions

	Type of action	Details	Results
1	Water Production Plants computerized	On Line Production Operation	Finalized in 2003
2	Water Production Plants Metering	Setting up the Water Production Plants Metering allows us to enhance the control of the produced water flow	Finalized in 2003
3	Pumping Stations Rehabilitations	These rehabilitations have permitted to decrease the pressure and to work in an automatic way	Decreasing Pressure

	Type of action	Details	Results
4	Water Pipes renewal (replacement)	Replacing our pipes increases the water quality, reduces our losses.	80 km replaced (2001-2005)
5	Valves renewal (replacement)	Replacing our valves allows us to repair our losses and to set up some district areas	4000 valves renewed
6	Leakage repairs	Repairing leakages increases our technical and billing output	55 000 reparations, reduction of the stock
7	Leakage Correlation	Finding Hidden leaks by phonical correlation	500 correlated kilometers
8	GIS	Geographical Information System: Putting in an informatics support the network	All the water network recorded in the system
9	Illegal Connections	Identifying Particular House illegal connections	5000 connections found

The total value of these actions is of about 26,000,000 €.

2.3.2. *Organizational measures*

2.3.2.a. Reduction of the water losses in WTP

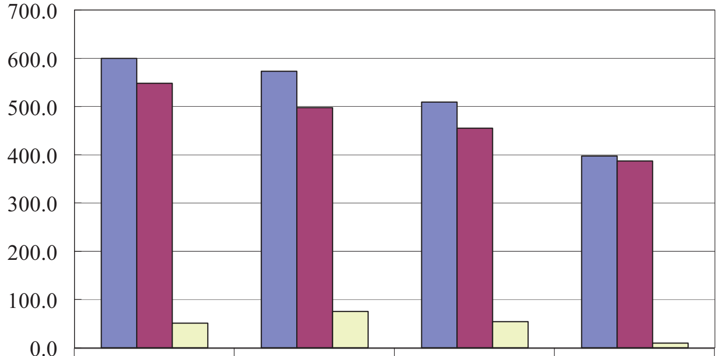
Measures were taken in the WTP in order to reduce the technological losses; among these it can be mentioned:

- rehabilitation of filters including the equipment for washing (contract of 2002 with development until 2005 for both WTP)
- valves replacement on the production flow (both WTP);
- installation of devices for regulating the water level at filters;
- equipment for the preparation and injection of poly-electrolytes into the treatment network (deadline 2005).

The obtained results are present in the figure 1.

2.3.2.b. Reduction/minimization water demand for supply systems through leakage detection and remediation

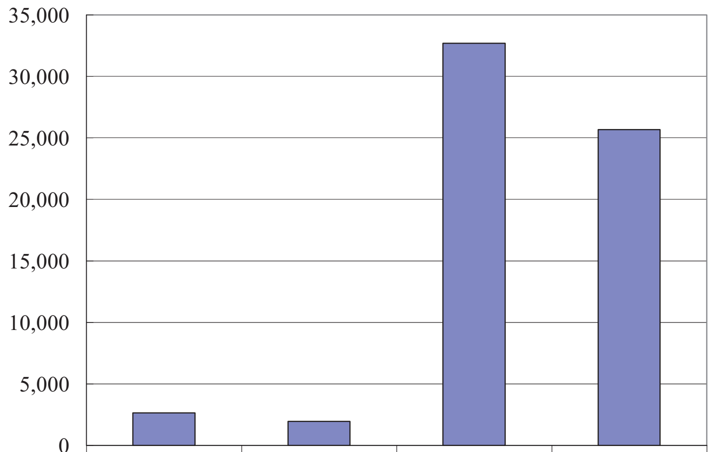
An important part of the investments has been dedicated to the replacement of the water pipes (figure 2), taking into account the important number of damages with water losses (figure 3).



	2001	2002	2003	2004
Raw water, Mm3	599.5	573.1	509.0	397.1
Produced water, Mm3	548.2	497.7	454.9	387.4
Difference	51.3	75.4	54.1	9.7

Raw water, Mm3 Produced water, Mm3 Difference

Figure 1 Evolution of the volumes of raw water, produced water and losses in the WTP's



	2001	2002	2003	2004
Replaced water pipes, m	2,630	1,951	32,687	25,663

Figure 2 Evolution of the length of the replaced water pipes

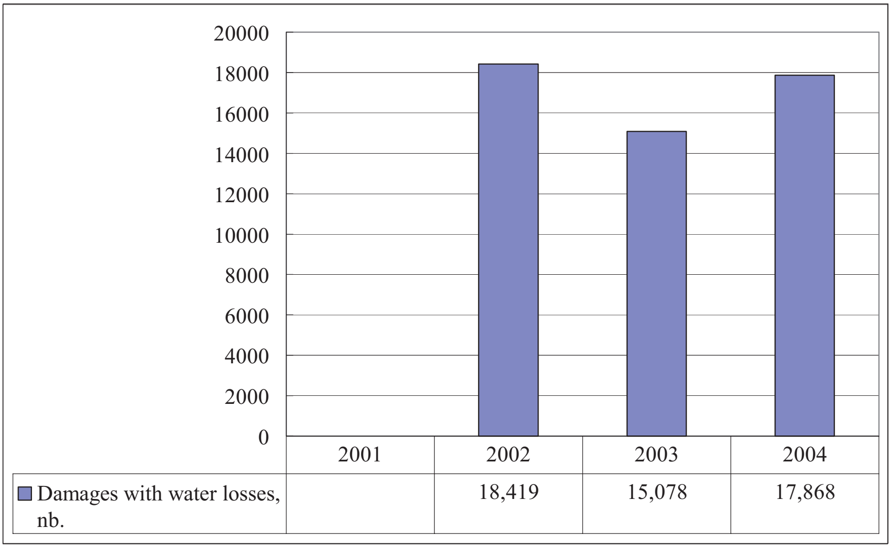


Figure 3 Evolution of the number of damages with water losses

The number of performed intervention in the system has decreased (figure 4).

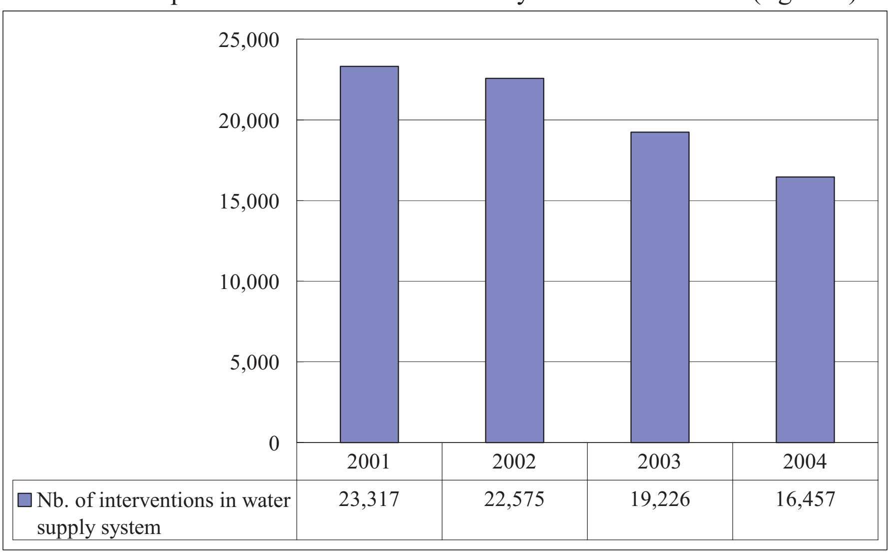


Figure 4 Evolution of the number of interventions in the water supply system

Important efforts were done to increase the speed until the intervention after announcement/detection and to reduce the time of the interventions. This has allowed a reduction of the stock of leaks (figure 5).

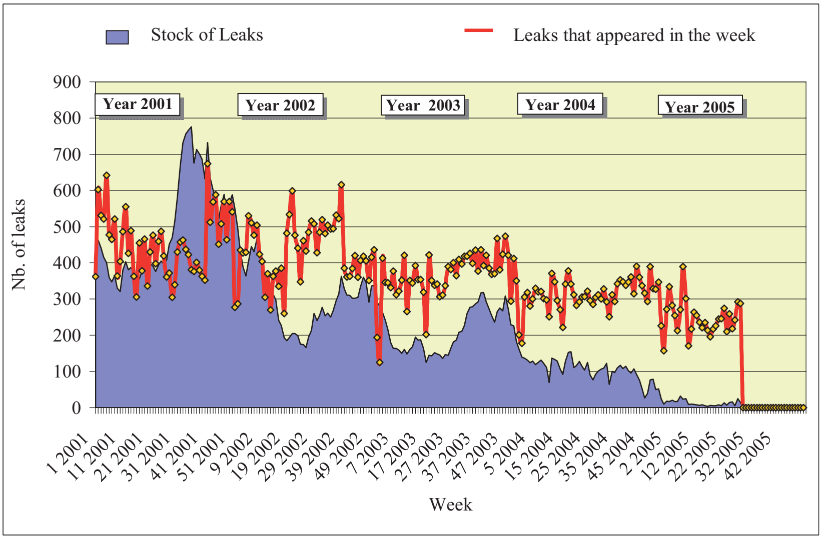


Figure 5 Weekly evolution of the number of leaks that "appeared" and of the "stock of leaks" during the period 2001 - 2005

Two other important actions were associated at the above efforts for the improvement of the situation of the water supply system of Bucharest: rehabilitation of re-pumping and booster stations (having as results the avoidance of the pressure shocks and reduction of electrical power consumption (figure 6)) and replacement of the water meter (figure 7).

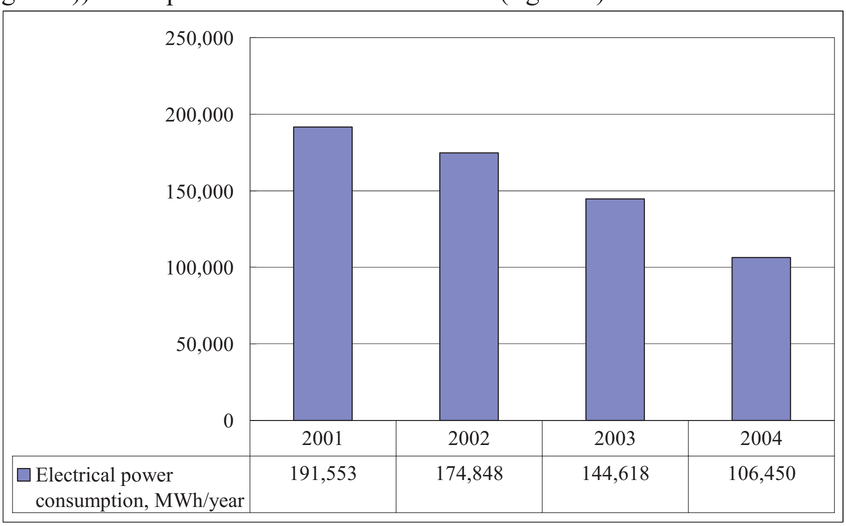
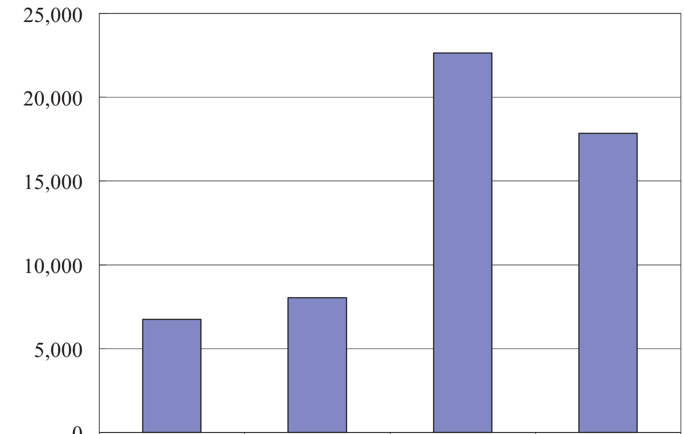


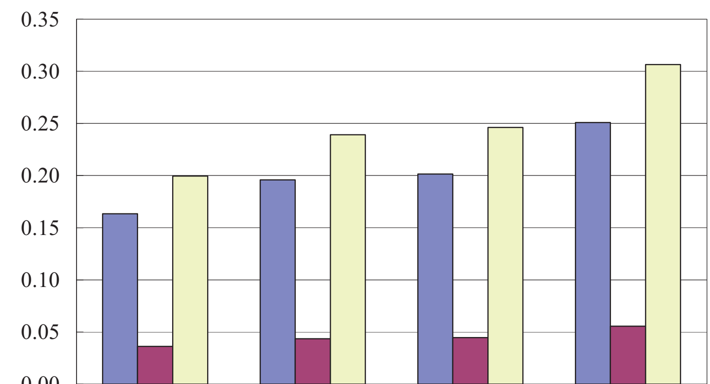
Figure 6 Evolution of electrical power consumption



	2001	2002	2003	2004
Replaced water meters, nb.	6,747	8,031	22,633	17,846

Figure 7 Evolution of the replaced water meters

All these were possible in the conditions of a low tariff (the tariff for water and sewerage services are on the 18-th place among the tariffs of the main Romanian cities) (figure 8) and a relatively constant turnover (figure 9).



	2001	2002	2003	2004
Water supply, Euro/m3	0.16	0.20	0.20	0.25
Sewerage, Euro/m3	0.04	0.04	0.04	0.06
Total, Euro/m3	0.20	0.24	0.25	0.31

Figure 8 Evolution of the tariff

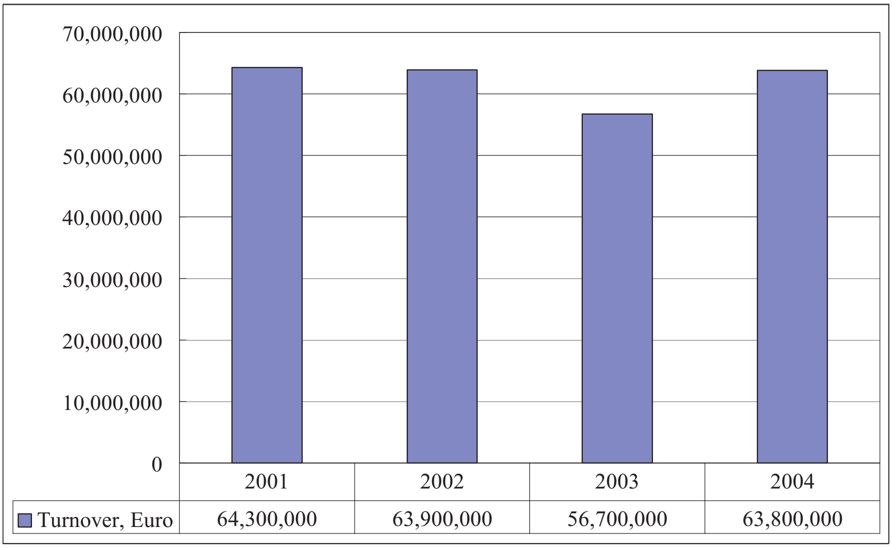


Figure 9 Evolution of the turnover

2.3.2.c. Implementation of water reuse

Apa Nova, through the Rosu Pilot Plant, is participated in the AQUAREC Project "Integrated Concepts for Reuse of Upgraded Wastewater". In the frames of this project a feasibility study for reuse technological wastewater in the Rosu Water Treatment Plant has been elaborated and, making allowance of capital costs (approximately 1,715,975 euro) and of short period for realization (14 months), it perhaps can be considered that the investment can be financed from own sources of Apa Nova in the next period.

3. The Future of the Water Supply of Bucharest

According to the forecast cash receivables, the investment program will be continued on premises comparable to the ones in 2004, both for the technical improvements and for the commercial ones. The largest investment part will be allocated to network renewal and extension.

Moreover, in 2005 the works for the site of the new potable water treatment plant of Crivina-Ogrezeni will have to be finalized. This modern plant will supply, as early as 2006, water of a perfect quality according to the most modern standards. Bucharest will then enjoy real safety in potable water supply, as a European capital should.

WATER SUPPLY IN CITIES OF BELARUS: WATER QUALITY AND RISK ASSESSMENT

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Abstract. In the paper different types of water supply systems in cities of Belarus and the quality of drinking water are discussed. Problems associated with intakes from pressure and non-pressure water-bearing horizons and surface water are described. Factors of drinking water pollution, including initial water chemical composition and current condition of water distribution system are analyzed. The peculiarities of groundwater pollution within urban areas, its main contaminants, spatial structure and dynamics are shown on the examples of Svetlogorsk and Polotsk cities. Ecological risk connected with consumption of polluted drinking water is assessed on the basis of concept of reference doze. The interrelated problems of groundwater pollution, safety water supply and food production are shown.

Keywords: water supply; groundwater; pollution; water quality; risk assessment

1. Introduction

Belarus is fairly well-supplied with water resources. The total river flow during years with medium water makes up to 58 km^3, out of which 34 km^3 (64%) is formed within the country. During years with low water content, the total river flow respectively decreases to 37.2 and 22.8 km^3.

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Natural resources of fresh underground waters (with mineralization up to 1 gram per liter) amount to 15.8 km³ per year. Annually about 1700 million m^3 of fresh water are used for different purposes. The main purpose of water consumption is for drinking and household needs (46% of total water consumption) (Environmental Protection…, 2005; Forecast of Environmental…, 2004). Daily water consumption rate in Belarusian cities is 180-370 liters per person (an average of 218 liters), which is significantly higher than in most European countries, it reaches 120-150 liters per person.

Belarus has relatively good water supply per capita. During years of medium water content, water supply in Belarus is 5,800 m³ per capita (for comparison: in the Ukraine – 1,700 m³; in Poland – 1,700 m³; in Lithuania – 6,800 m³) (Apatsky et al, 2003). Overall, Belarus has considerable underground water resources that are several times higher than their contemporary and prospective consumption. Currently only 27% of explored underground water resources in the country are consumed (State water…, 2005).

At the same time the quality of drinking water is an acute problem. On the one hand, it is caused by specific qualities of natural waters in Belarus; on the other – by contamination of underground and surface water sources. In particular, among natural characteristics of underground waters high content of iron and manganese, as well as increased hardness are worth mentioning.

The highest concentrations of iron are recorded in subsoil waters of bog deposits (up to 20-40 mg/l). Increased concentration of iron (0.4-3.0 mg/l) is observed in forcing water-bearing stratums practically all over the country, and its highest value reaches up to 5-8 and sometimes 10-15 mg/l (Gurinovich, 2001).

The quality of drinking water is greatly affected by hygienic and sanitary conditions of sites surrounding water wells, of water treatment plants, as well as sanitary and technical state of water wells themselves. Following factors contribute to contamination of underground waters: most water wells are located within city limits and industrial districts; underground waters are located close to the surface; different water layers have tight hydraulic connection; in addition, underground waters are poorly protected.

2. Types of Water Supply Systems and Quality of Drinking Water

2.1. SOURCES AND TYPES OF WATER SUPPLY SYSTEMS

There are two types of water supply systems in Belarus: centralized and non-centralized. Centralized water supply is provided in 92 cities and towns. Thus, 75% of urban and 50% of rural population have access to centralized water supply. The remaining part of the population (32% of the total inhabitants of Belarus or more than 3 mln. people) uses water from mineshafts.

Underground water is the main source of water supply for drinking purposes. However, residents of Polotsk and partly of Minsk and Gomel cities receive their drinking water from surface sources. For instance, in Minsk 35% of drinking water supply comes from surface sources - 250,000 m^3 daily (Health of Population…, 2004).

Centralized water supply systems use forcing waters from the depth of 50-200 meters. Totally there are 155 group water supply points in the country. The most common methods of water treatment in Belarus are de-ironing and chlorination. The first method is used rather broadly, even though around 80% of municipal water pipes lack de-ironing stations. In Minsk region there are 14 functioning water de-ironing stations capable of treating of 138,000 m^3 water daily, which is 69% of the needed 200,000 m^3 (Lavrov, 2003).

Chlorination is primarily used in large cities in order to destroy bacteria and viruses. Yet, chlorination of waters with high content of organic substances leads to creation of chlorine-organic compounds, in particular chloroform (Health of Population…, 2004). Besides, chlorination leads to a specific taste and smell of water. Thus, Minsk has a multistage water treatment system, which includes primary and secondary chlorination, as well as ozone treatment and coagulation.

2.2. QUALITY OF DRINKING WATER FROM CENTRALIZED WATER SUPPLY SYSTEMS

The quality of centralized and non-centralized water supply sources is controlled by laboratories of sanitary and epidemiological agencies, which annually inspect thousands of them. For example, 14,000 sources of centralized and roughly 14,000 sources of non-centralized water supply were inspected in 2004. It was revealed, that in major cities drinking water does not meet hygienic standards: 30-78% of water samples taken from centralized sources failed to meet sanitary-chemical standards and 1-3% - microbiological standards set for drinking water. The main reason for failure was high concentration of iron, which leads to violation of color and clarity requirements. Overall, 51% of water samples taken from centralized water supply systems in 2004 were found to contain iron exceeding the maximum allowable concentration limits. Besides, several water wells fell short of meeting stickiness standards, and contained exceeding amounts of manganese, ammonium, nitrates and other substances (Figure 1).

Table 1 illustrates the quality of underground waters in wells located in Minsk.

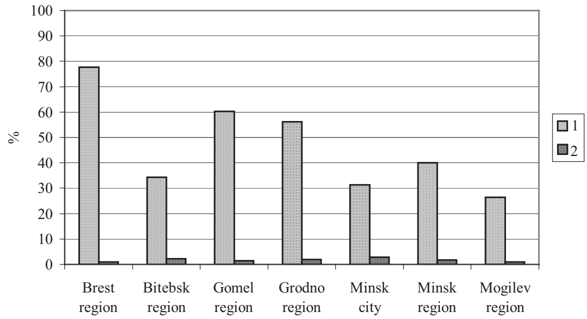

Figure 1 The share of water samples failed to meet chemical (1) and microbiological (2) standards for centralized water supply systems (by data State Water…, 2005)

TABLE 1 Contamination of underground waters of wells functioning in Minsk in 2004 (State of Environment…, 2005)

Water intake	Pollutants	Multiplicity of PCL exceed	Number of water supply wells with water pollution	Sources of pollution
Novinky	Nitrates	1.1-1.4	5	Battery farm, garage, old dump, hydro-geological condition
	Hardness	1.0-1.5	5	
	Nitrites	1.3	1	
	Boron	2.0-2.8	5	
	Barium	4.4	1	
	Chromium	1.5	1	
Draznya	Boron	3.2-3.7	3	Hydro-geological condition
	Fluorine	1.4-1.8	3	
Petrovshina	Boron	3.3-3.9	2	The same
	Fluorine	1.3-1.6	2	
Selenovka	Hardness	1-1.4	2	Hydro-geological condition, urban run-off
	Boron	1.1-3.6	2	
	Barium	2.5	1	
	Fluorine	1.1	1	
	Chromium	1-8.4	3	

Water treatment process improves the quality of water. However, even after this treatment, standards set for drinking water are not always met. For instance, primarily due to corrosiveness of water, transportation of water can cause increased concentration of iron.

According to (Mencha et al, 2003), in Baranovichi the water arrives to the water supply system from water treatment plants with iron concentration of

0.07-0.27 mg/l. In the distribution system iron content in the water is further increased to 1 mg/l as a result of iron bacteria activity.

Water distribution networks are worn down by 60% in Minsk and by 50% in Belarus. As a result water supply network can also serve as one of the sources of drinking water secondary pollution by bacteria and intestinal viruses. This is caused by the overgrowing of the inside of water pipes, as well as by creation of by-products during disinfection procedures and by existence of still-water zones in certain parts of networks, etc. According to (Drobenya et al., 2003), 32.5% of samples taken from Minsk water supply network failed to meet microbiological standards. However, such deviations were not recorded after the water has been treated in water treatment plants.

2.3. THE QUALITY OF WATER IN NON-CENTRALIZED WATER SUPPLY SYSTEMS (SHAFT WELLS)

Nitrates are the primary pollutant of water in non-centralized water supply systems. In 39% of all cases nitrates content exceeds the maximum allowable concentration limit (State Water…, 2005). According to (Loginov et al., 2002; Kudelsky et al., 1998), roughly 70% of shaft wells contain nitrates exceeding the maximum allowable concentration limit. Their concentration reaches sometimes up to 300-600 mg/l. This is a typical problem in villages and private residential areas of cities. The highest concentrations of nitrates were found in wells of the old city boroughs where, irrespectively of the season, the nitrate content exceeded the permissible concentrations limit (45 mg/l). Pollution of drinking water by nitrates is caused by household sewer. Most of the private houses in cities are not equipped with water drainage systems, and in most cases household fecal sewer is dumped into devour pits.

According to (Forecast of Environmental…, 2004), nitrates in underground waters are rather stable and capable of migrating to big depths. For instance, nitrate pollution of water at the Novinki water intake wells, located in Minsk, is recorded at the depth of 200 meters.

During a decade, the content of nitrates in the shaft wells water has noticeably decreased. This tendency is typical of all private residential areas in cities, and can be explained by the decrease of fertilizers usage on personal plots and agricultural lands.

According to (State Water…, 2005), significant part of samples taken from shaft wells does not meet chemical and microbiological criteria set for drinking water, even though in most cases this is characteristic to small towns and villages (Figure 2).

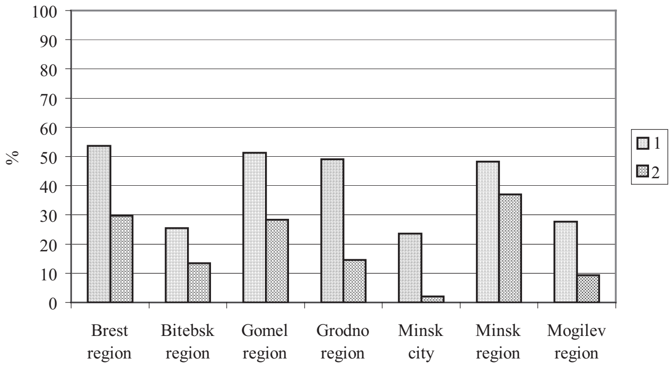

Figure 2 The share of water samples failed to meet chemical (1) and microbiological (2) standards for non-centralized water supply systems (by data State Water…, 2005)

We have examined the chemical composition of the upper water-bearing stratums in private residential areas of several Belarusian cities, including Svetlogorsk, Polotsk, Beresovka and Baranovichi. We have revealed that the upper water-bearing stratum is most often characterized by increased mineralization (more than 500 mg/l), as well as by significant excess of background concentrations of virtually all components of macro-composition. The highest recorded content of chlorides is 112 mg/l, sulfates – 450, sodium – 188, magnesium – 109, potassium – 45, ammonium nitrogen – 88 and nitrates – 93 mg/l. Reaction of waters varies from neutral to low alkaline. The initial zonal composition of water is often disturbed. In several cases sulfate-hydrocarbonate and magnesium-calcium compounds were revealed.

3. Pollution of Underground Waters – Space Structure

It is well known that chemical composition of natural waters is formed as a result of interaction of natural factors and human activities. In all towns, and in particular in larger cities, human activities become a determinative factor in the process of formation of natural waters chemical composition, the geochemical character of which transforms drastically (Kudelsky et al., 1998; Loginov et al., 2002; Khomich et al., 2004). Pollutants enter the underground waters because of the imperfection of the technologies used, sewage cleaning; spillage of pollutants during their transportation, filtration of polluted waters from sludge storages and filtration fields, etc.

The multitude and great variety of contamination sources in cities and hydro-geological aspects of a particular territory determine the complex structure of underground waters pollution fields.

We have analyzed the space structure of underground water contamination in Polotsk and Svetlogorsk cities.

The great diversity of chemical composition of the upper water-bearing stratum was revealed. The figure 3 illustrates the correlation between different components of macro-composition on a relatively small territory – one district of Polotsk city.

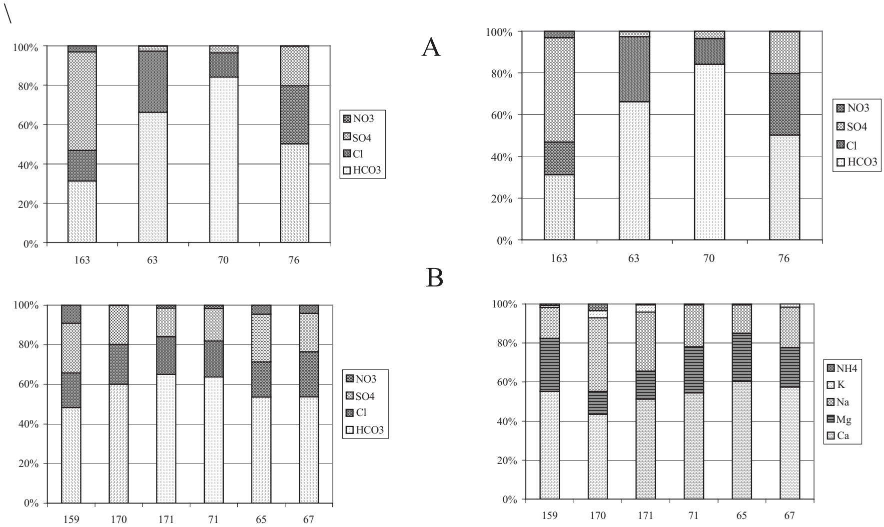

Figure 3 Correlation of ions in subsoil waters in Volovo district of Polotsk: A – samples taken from wells; B – samples taken from bore pits

Even higher diversity in chemical composition of underground waters was revealed while analyzing the city as a whole. Thus, the investigation in Svetlogorsk city showed that hydro-geochemical anomalies, different in genesis, area and pollutants content, had been formed within the city territory and its impact areas. In respect to anion ratio and pH value, the following types of underground waters pollution were singled out: nitrate water pollution in dwelling areas (the associated component in a number of cases is iron); sulfate underground waters pollution in the impact area of Khimvolokno Amalgamation; treatment facilities and the industrial wastes polygon; chloride-sulfate water pollution on the industrial site of Khimvolokno Amalgamation; hydrocarbonate-chloride water pollution in the impact area of the household wastes polygon; pH water increase in the impact area of the Heat Power Station (areas of alkali waters spreading). As a result of water quality assessment, places with non-suitable water for different purposes were reveled (Figure 4).

Figure 4 Underground water pollution. Exceedance PML for main ions, times: 1 - <1; 2 - 1-2; 3 - 2-5; 4->5. Sampling sites: a – bore holes of Khimvolokno Amalgamation , b – bore holes of Heat Power Station, c –bore holes of municipal sector near the dump of solid domestic wastes, d - wells, f – soil bore pits

In general, the correlation between the chemical composition of water and types of influence can be easily traced. Almost everywhere in cities, the pollution of the upper water-bearing stratum, and in some cases, of forcing water-bearing stratums suggest that it is dangerous to locate sources of water supply on city territories or areas of local impact sources.

4. Environmental Risk Evaluation

It is highly likely that people living in areas with contaminated underground waters will consume the pollution. There are two basic ways of this consumption: either by drinking the contaminated water, or by eating agricultural products grown on lands where underground water is close to the surface.

The results obtained show the existence of several types of environmental risk on the territory of Svetlogorsk city and its impact areas: risk related to tap water pollution with iron and suspended substances; risk related to water consumption from shaft wells in the individual household areas; risk related to consumption of vegetables and other agricultural products cultivated in areas with polluted ground waters.

Water pollution in shaft wells that is used for drinking purposes represents the largest hazard. We used the value of 21 ml/kg body mass a day as an average water consumption norm for the ecological risk evaluation of the population consuming water from shaft wells (Exposure Factors…, 1997). According to the data obtained, nitrate entry in water for the city inhabitants can make up to about 1.7 mg/kg a day, while permissible dosage is 1.6 mg/kg a day. The ecological risk for the population can increase in case of consumption of vegetables and other agricultural products polluted with nitrates (Khomich et al., 2004).

The ground waters pollution with heavy metals including zinc takes place on the bogged area between the industrial site of Khimvolokno Amalgamation and sludge storages. This area is extensively used by the population to grow vegetables and potatoes and thus, there is a hazard of zinc and other toxic elements entering into food chains.

Sampling and analysis of vegetables showed their considerable pollution with zinc on the area under study. Zinc mean concentration in vegetables made up to 77.6 mg/kg. For mean norm of vegetable consumption 4.3 g/kg of body mass a day (Exposure Factors…, 1997) a dosage for zinc makes up to 0.33 mg/kg body mass a day. It is a bit higher than the permissible dosage of oral zinc consumption equaled to 0.3 mg/kg of body mass a day.

On the whole, the prevention of groundwater pollution, safety of water supply and food production are interrelated problems that should be taken into account in urban water management and planning of land use.

5. Problems of Improving the Quality of Drinking Water

One of the main problems of drinking water quality improvement is the functioning of group water intake wells and creation of huge depression funnels. This can lead to the arrival of brackish and salty waters from lower stratums and pollution of underground waters from surface sources. In order to avoid this situation, the method of group wells must be abandoned, and instead - single, separately located water wells must be created.

The majority of water intakes are located within city limits and industrial districts. 14% of water wells have no strict water protection zones. It is necessary to improve sanitary conditions of areas around water wells and to limit agricultural activities in their neighborhood.

One of the ways to improve the quality of drinking water is to build de-ironing stations and use new technologies (including steady materials) while building and repairing wells and water distribution systems. It is also necessary to improve sanitary conditions of areas around water wells and to limit agricultural activities in their vicinity.

It is important to assess and increase the scope of monitoring of topsoil pollution level, underground and surface waters. Additionally, quality control of drinking water in water pipelines is necessary.

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RISK ASSESSMENT OF POTABLE WATER USED FROM RIVER INTAKES NEAR RADIATION-DANGEROUS OBJECTS (OBNINSK FOR ILLUSTRATION)

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Abstract. Coupling of natural and anthropogenic factors reduces water quality to the values exceeding sanitary and hygienic standards. Near to radiation-dangerous objects a threat is represented with pollution of groundwater technogenic radioisotopes, including tritium. In Russia not enough attention is given specifications under contents tritium and etc. radionuclides in potable water. For an establishment of a degree of influence on the person tritium and chemical pollutants it is convenient to use health risk assessment in its ingress into the human body.

Keywords: river valley intakes; piezometric depression; water quality; tritium; heavy metals; health risk

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1. Introduction

Obninsk is situated in Kaluga region 100 km south-west of Moscow on the left bank of the Protva river. Several enterprises utilizing nuclear energy are operating in the town. The primary effects associated with Obninsk radiation-dangerous objects are gas and aerosol releases into the atmosphere, liquid waste discharges into the Protva river and groundwater pollution.

2. Characterization of Groundwater of Obninsk

Municipal intakes involve 34 wells arranged 15 km apart in a sequence north-south along the foot of the left slope of the Protva river valley. Northern and southern water intakes are upstream and downstream of the town, respectively. They belong to river valley intakes with mixed feeding, i.e. precipitation infiltration is responsible for a smaller part of groundwater and a greater amount is being formed by overflowing from Protva. Water reserves are maintained by the Protva river runoff, the volume of which depends on the precipitation fallen out and watershed area.

Groundwater reserves in the intakes upstream of the town are much smaller as compared to those located downstream as feeding in the latter case is maintained also by a runoff of the Luzha river, a large tributary 1000 km^2 in area.

Water production actually is distributed between municipal intakes just “on the contrary”, i.e. three fourth of water is drawn from the northern intakes and only a third from the southern one in Dobroe. Such a “disrepancy” in groundwater production has caused more than 40 m lowering in a piezometric level of the industrial water bearing horizon for the very northern intake in Vashutino. Along Obninsk intakes in an industrial water bearing horizon formed was a hydraulic slope directed upstream opposite to the natural runoff of surface and groundwater. The inverse flow of river water ingressing into a groundwater bearing horizon, on the one hand, compensates the depletion of groundwater reserves in the northern intakes and, on the other hand, gives rise to the conditions of pollutant transfer from the Protva river into municipal water intakes as shown by Silin (2003).

Piezometric depression has changed hydrodynamics and geochemistry of groundwater and is one of the reasons for dewatering of the upper water bearing horizons, the rocks of which turned out to be in the aeration zone. Rock oxidation in the aeration zone has stipulated the ingress of oxidation products into groundwater. Industrial and domestic wastes, the outlets for which are arranged in the south and downstream of the town, partially enter the northern intakes together with an inverse flow of river water.

Coupling of natural and anthropogenic factors has reduced water quality to the values exceeding sanitary and hygienic standards (Table 1).

TABLE 1. Volume of contaminated water (with MPC excess in corresponding risk indices) produced in 1999 from Obninsk intakes

Intakes	Total production in 1999 [thous. m^3]	(Including harm indices exceeding MPC, thous.m^3)					
		General sanitary					
		Colour	Turbidity	Oil	General rigidity	Total	Fe
Vashutino	12906	5185	1205	0	3255	9645	1688
Samsonovo	2867	909	796	114	796	2615	1194
Dobroe	4248	1503	1503	570	207	3783	1088
Total	20021	7597	3504	684	4258	16043	3970
Total (%) of 20021		37.9	17.5	3.4	21.3	80.1	19.8

TABLE 1 (continued)

Intakes	Total production in 1999 [thous. m^3]	(Including harm indices exceeding MPC, thous.m^3)						
		Organoleptic			**Sanitary-toxicologic**			
		Mn	Cu	Total	F (>1.5mg/l)	Sr	Benz(a)) pyrene	Total
Vashutino	12906	121	121	1930	1326	5305	3376	10007
Samsonovo	2867	171	57	1422	171	1904	1421	3496
Dobroe	4248	0	0	1088	0	0	2592	2592
Total	20021	292	178	4441	1497	7209	7389	16095
Total (%) of 20021		1.5	1	22.2	7.4	36	36.9	80.4

3. Radioisotope Groundwater Contamination and Health Risk Assessment

Despite nuclear specialization of large enterprises in Obninsk, radioisotope groundwater contamination is still not clearly understood so far as radiation monitoring of groundwater is not being conducted in wells of the regional and federal network.

Groundwater contamination with tritium was first detected in a sanitary-protective zone of the Institute of Physics and Power Engineering (SRC-IPPE) by Roshydromet researchers when realizing the “Program of radiological monitoring in the territory of nuclear industry enterprises” as shown by Makhon’ko (2001).

A comprehensive survey of the institute’s industrial site and adjacent territories has revealed that research nuclear reactors and accelerators where tritium targets are applied as well as radioactive waste storages are considered to be the sources of technogenic tritium. All the above sources are located within the sanitary controlled area of intakes. The expected release of tritium into the environment by this enterprise ranges from $2.5 \cdot 10^2$ to $2.5 \cdot 10^3$ Ci/year as shown by Starkov and Moiseeva (2001). Table 2 presents data on tritium activity in water of springs and wells near SRC-IPPE.

TABLE 2 Results of tritium measurements in water samples for September 2004

Sampling site	Specific activity, Bq/l
Water well №1	452
Observation well № 8	223
Water well in the village Peredolje	32.2
Spring №7, Konchalovsky hills	17.4
Spring № 50 near industrial site	109
Protva river oxbow near industrial site	3200
Obninsk water-supply network	102

The observed values of tritium activity are below the intervention levels (7700 Bq/l for inorganic compounds and 3300 Bq/l for organically bound tritium). It should be noted, however, that according to the US Environmental Protection Agency (US EPA) recommendations the intervention level of tritium in potable water is 740 Bq/l, i.e. by an order of magnitude lower as compared to this parameter in Russia. This suggests that little attention is being given to tritium in our country and the present-day standards for tritium may have to be revised. One of the risk criteria for such radionuclides as tritium is its health risk assessment in its ingress into the human body.

The risk was being assessed to establish the effect of considered tritium concentrations on human health. Data on tritium concentration in pipe-line drinking water for September 2004 were used for calculations. The activity of ^3H amounted to 100 Bq/l and corresponded to the risk of such water consumption ~ $3 \cdot 10^{-7}$ year^{-1}. The risk value given in magnitude is close to the individual annual death risk for population living near NPP – $7 \cdot 10^{-7}$ year^{-1} as shown by Bolshov et al., (2001) and at the same time corresponds to the level of tolerable risk (10^{-6}) and falls within “risk optimization”, i.e. in the sphere for planning the economically sound measures on exposure risk reduction.

4. Chemical Risk Assessment

To estimate the chemical risk, physical and chemical analysis was made of all springs near SRC RF IPPE. The concentrations of basic cations and anions in carbohydrate-calcium water, pH, mineralization and general rigidity were also determined. In addition, the concentration of microelements given in Table 3 was also estimated.

TABLE 3. Geochemical composition of spring water

	General rigidity, mg-eqv/l	Concentration, mg/l									
		Ag	As	Al	Be	B	Cd	Hg	Pb	Cr	Zn
MPC	7.0 (10)	0.05	0.05	0.5	0.0002	0.5	0.001	0.0005	0.03	0.055	5.0
Spring	5.7	0.001	0.01	0.11	<u>0.0006</u>	0.014	<u>0.021</u>	<u>0.003</u>	0.010	<u>0.061</u>	0.017

Note: concentrations exceeding MPC are underlined

The assessed quality of spring water has shown that heavy metals, the concentration of which exceeds MPC are considered to be the primary pollutants. Chemical contamination risk for groundwater was estimated according to the US EPA technique (EPA, 1996). In spring water consumption the risk of carcinogenic diseases amounts to 0.004. According to the classification accepted the health risk in case of spring water consumption is inadmissible.

5. Conclusion

The compared assessments of risk associated with tritium exposure, on the one hand, and the dangerous chemical (e.g. heavy metals) contamination of Obninsk spring water, on the other hand, have confirmed that just these chemical pollutants are responsible for health risk. It means that the risk stipulated by these pollutants found in water is by four orders ($5 \cdot 10^{-3}$, as shown by Synzynys et al., 2004) higher as compared to the risk associated with the chronic exposure of population using water with increased tritium contents.

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URBAN DRAINAGE AND WATER BODIES

WASTEWATER NETWORK CHALLENGES AND SOLUTIONS

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Abstract. Sewer and storm water systems in cities worldwide suffer from ageing and inappropriate wastewater networks. This challenge has to be met by systematic upgrading and preventive maintenance. It is necessary to analyse the current performance of the wastewater networks, to determine the system bottlenecks that cause system vulnerability on floods in city areas and pollution of receiving waters. The next task is then to use this information for selecting and ranking upgrading projects to improve the situation. CARE-S is a computer based system developed to meet this challenge. It is designed for sewer and storm water network rehabilitation planning. It provides fundamental instruments for estimating the current and future condition of sewer networks,

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i.e. performance indicators, selecting and ranking of rehabilitation projects and long-term investment needs. The procedure for selection and ranking of projects is supported by tools for analysis of structural failures and hydraulic performance. Socio-economic issues are also included in the priority ranking process of CARE-S.

Keywords: sewer networks; rehabilitation; rehabilitation technology; performance indicators; pipe condition; hydraulic performance, strategy.

1. Background

Sewer and storm water systems in cities worldwide suffer from insufficient capacity, construction failures and pipe deterioration. The consequences are structural damage and local floods leading to inflow of water into basements, traffic disturbances, street and surface erosion, and pollution of local receiving waters.

The reasons for the problems are the combined effects of ageing infrastructure, urbanisation and climate change. European cities spend in the order of 5 billion € per year for wastewater network rehabilitation. This amount will increase significantly over the coming decades, due to network ageing.

Today, the rationale behind rehabilitation decisions is unclear. Decisions are often made ad hoc and, in the best case, are based on practical experience after failures appear (reactive approach). This was the background for a project in the 5th Framework Programme in EU, Computer Aided Rehabilitation of Sewers and Storm water networks (CARE-S). The project objective was to establish a rational framework for sewer network rehabilitation decision-making**.** CARE-S aimed to improve the structural and functional reliability of the wastewater networks (risk of in- and exfiltration, collapse and blockage due to pipe deterioration, hydraulic overloading resulting in flooding and/or receiving water pollution). The ultimate product has become a three-tier Decision Support System (DSS) that will enable municipal engineers to estimate long-term investment needs, select and rank concrete projects and choose the best technology for the selected project. In other words: *Rehabilitate the right sewer at the right time by using the right rehabilitation technique at a minimum total cost, before serious failures occur (pro-active approach)*.

The objective of CARE-S was to develop a number of analysis tools, link them and to make them usable for the formulation of a rehabilitation strategy. The CARE-S system includes the following elements (Fig.1):

- a tool generating Performance Indicators (PI) that are relevant for rehabilitation decisions, including analytical and statistical procedures to assess and forecast some of the PIs
- a procedure to define the socio-economic and environmental risks of malfunctioning sewer systems
- a database to be used for choosing an appropriate rehabilitation technology
- a tool to define the best long-term strategy for rehabilitation investments
- several tools that allow to assess the hydraulic, environmental and structural conditions of the network including their change over time.
- a multi-criteria decision (MCD) tool supporting the choice of high priority rehab projects
- a software package, called "Sewer Rehab Manager" that will enable consultants and wastewater service providers to use the above products according to their individual needs and available data base.

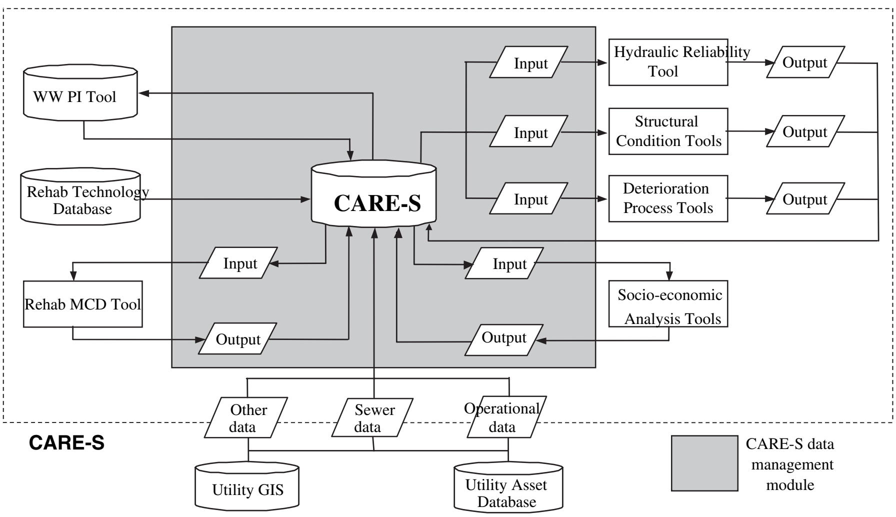

Figure 1 The general architecture of the CARE-S Sewer Rehab Manager

The final outcome of CARE-S is fourfold; condition of network, long-term investment need, selection and ranking of projects and choice of technology. The PI system provides a very strong facility for the network condition analysis, trends and benchmarking. The benchmarking can be done versus other cities or as a comparison between districts. It is very well suited for communication with political authorities. Secondly, the long-term investment needs can be supported by trend analysis, benchmarking assisted by a model for temporary decline of the networks. When the long-term investment framework is established the next challenge is to define and rank projects. In CARE-S, this is supported by analysis of structural, hydraulic and socio-economic performance. Finally, when a project has been selected, there is a tool for the selection of technologies, supported by a technology database (Sægrov et al., 2005).

2. Results

The CARE-S system for wastewater rehabilitation planning is readily developed and has been tested by a number of cities representing all parts of Europe and also Australia**.** A brief explanation of the system is given in the following pages.

2.1. CONSTRUCTION OF A CONTROL PANEL OF PERFORMANCE INDICATORS (PI) FOR REHABILITATION

A PI (Performance Indicator) tool addressing information relevant for sewer and storm water network rehabilitation has been developed. It is based upon comprehensive and quality-controlled information from 32 project partners and end-users. The final listing includes 41 PI in total. Additionally, a large number of Utility Information (UI) and External Information (EI) have been included in the system.

The general criteria for selecting PI for wastewater rehabilitation were among others (Matos et al., 2003; Cardoso, 2005):

- to represent relevant rehabilitation aspects of wastewater undertakings performance, allowing for a global representation of the system by a reduced number of performance indicators
- to be clearly defined with a concise meaning and a unique interpretation for each indicator
- to be auditable, which is specially important when the performance indicators are to be used by external bodies (i.e. regulators) that may check the results reported.

A questionnaire to verify 35 pre-selected PI was answered by 13 partners and 20 end-users. The receivers were asked to rank the PI regarding importance and assess. Based on the answers, the list of PI was extended to 41.

The questionnaire revealed that partners tend to overestimate the importance of PI in comparison with end-users. In general, the partners also tend to be more "optimistic" than end-users concerning the PI assessment.

PI relies on qualified definitions. Therefore, a glossary of rehab terms has been developed. It includes mainly a set of definitions referred in European Standards, with some additional definitions from WRc Rehabilitation Manual.

2.2. DESCRIPTION AND VALIDATION OF TECHNICAL TOOLS FOR STRUCTURAL CONDITION

An analysis of CCTV data classification has been launched. This is used as the input to high level models dealing with the entire system as well as detailed structural models of blockages and in/ex-filtration that are currently being developed.

The structural condition of a pipe depends on material, construction practices, external load and wastewater characteristics. Previous research has shown that pipes laid within certain time periods have been structurally under-designed, and that construction practices within some time periods have not been appropriate, thus leading to particularly frequent failures. The formation of hydrogen sulphide that occurs in some wastewater networks from anaerobic decomposition of organic mater compounds or from reduction of mineral sulphides will lead to a microbiological deterioration and loss of strength for concrete sewers, and is a very important reason for rehabilitation actions. Other reasons are root intrusion and substantial in- and ex-filtration through fissures and leaky joints (Knolmar and Szabo, 2003; Vollertsen 2005a,b).

Structural analysis of sewers is normally based on results from CCTV inspection. In Europe there are several systems currently being used for the classification of individual data from such investigations. A standard European code for the description of sewer damages has been introduced and recommended to the Member States. In general, the condition of sewers is classified according to its most severe damage or overall condition to determine the urgency of rehabilitation and to calculate the cost of rehabilitation.

In CARE-S, different models for the classification and assessment of the sewer condition were analyzed and tested with CCTV data together with other types of data, provided by end-users. Aggregated models deal with the entire network. They calculate the distribution of condition classes, and are applied to networks. Detailed structural models deal with issues important for the hydraulic performance and structural condition on a local (pipe based) level and are applied for single pipes or group of pipes (Legat, 2004). They comprise structural failures, strength reduction due to hydrogen sulphide attack, pipe blockage and in-exfiltration of water. The models are developed or improved and calibrated with such data from the end-user sewer networks. The models allow a forecast of the year in which a sewer will fail or enter a critical class of condition, thus determining the next inspection date or rehabilitation measure. An overview of models is presented in Figure 2.

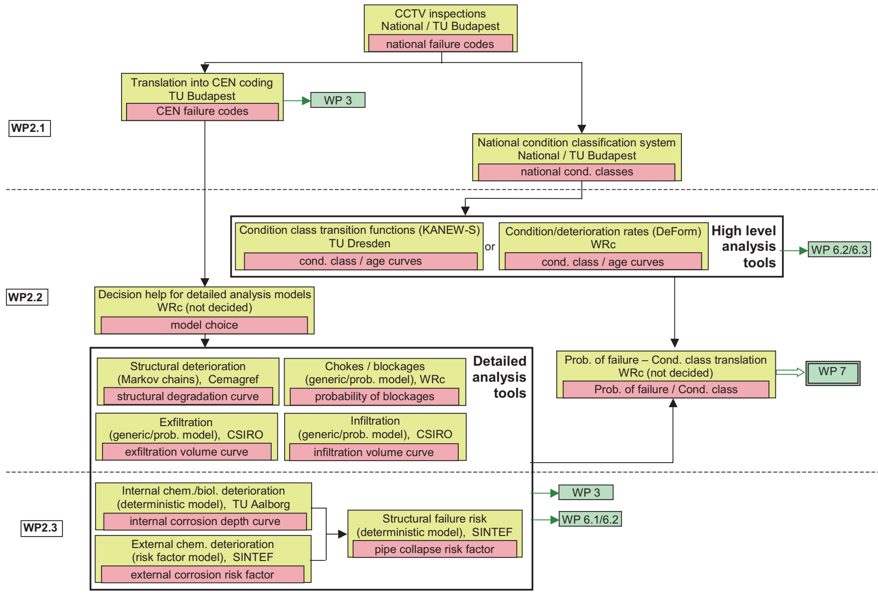

Figure 2 Overview of models for structural assessment of wastewater networks

2.3. DESCRIPTION AND VALIDATION OF HYDRAULIC PERFORMANCE

Structural decline of sewers is described by CEN-code classes (e.g. obstacles, roots, displacement of joints, intruding pipes). Their hydraulic effects are modelled using software for 3D analysis (FLUENT) and "translated" into a simplified 1-D description for application in hydraulic models such as MOUSE, InfoWorks, and SWMM.

A study on best practise on wastewater modelling has demonstrated that single models have reached high levels of reliability. Still further progress is needed on model integration in order to achieve a global control on urban water analysis. It has be decided to include three 1D models as basis for routines develop within CARE-S, namely MOUSE, InfoWorks and SWMM (Freni et al, 2003; Milina et al., 2004).

The second task comprises the modelling of temporal decline of hydraulic performance using CCTV observations and a 3D CFD software (FLUENT) for parameterization and validation of 1D hydraulic model (MOUSE, InfoWorks, SWMM). Test models at catchments of Palermo, Reggio Emilia and Oslo have been prepared for the testing of the routine that is developed in this work package, and the testing is promising.

As the third task, a procedure was developed for assessing compliance of the sewer system with the environmental standard/target/threshold specified by the end-user (effects of rehabilitation works on ground and surface water) using conceptual infiltration/ex-filtration models (Schulz and Krebs, 2004).

The results on hydraulic performance are also connected to analysis of changes in future structural performance that may affect the hydraulic capacity, and socio-economic consequences. This integration makes it possible to analyse future hydraulic performance and the consequence related to flooding in sensitive areas.

2.4. REHABILITATION TECHNOLOGY INFORMATION SYSTEM

An extensive rehabilitation technology database including available techniques, their advantages, disadvantages and application possibilities has been developed.

There are a variety of methods to rehabilitate wastewater networks. The method to be chosen obviously depends on local conditions, such as the type of the problem, the size of the pipe etc. The rehabilitation costs are linked to the applied method and technology (Hlavinek et al, 2005; Montero et al, 2004).

The content of the rehabilitation technology information system can be summarized as:

- General survey of available techniques. Analysis of experiences and results.
- Complete database for the variety of methods in rehabilitation of sewers. Current state-of-the-art, including rates, range of applicability, limits and restrictions.
- Cost of rehabilitation linked to the applied technology.
- Alternatives for rehabilitation: redesign of sewers, operational methods.
- Criteria for choice-making of suitable techniques related to sewer problems.

Rehabilitation of sewer and storm water networks includes system improvements (detention basins, separation of storm water etc) as well as renovation technology. During the last 20 years, there has been an extensive development of technologies for sewer and storm water rehabilitation. Today, a large variety of methods exist to meet problems in small sized as well as large sized pipelines. Several cities use renovation as their first priority measure against structural and hydraulic decline.

By using the database, the end user is invited to analyze which measures are appropriate to meet various kinds of problems. A list of measures and problems they should apply to is presented, considering their potential for pipe failure in one hand, and their characteristics leading to more or less social disturbance and annoyances on the other hand.

Also, attention has been brought to the innovative question of establishing the explicit links between the rehabilitation techniques (with or without trench) and the other aspects of wastewater rehabilitation, such as disturbances to the citizens, hydraulic benefits, mechanical benefits, and economic issues.

2.5. SOCIO-ECONOMIC CONSEQUENCES

Socio-economic consequences including rehabilitation impact on socio-economic costs, impacts on quality of life, public acceptance and communication with public are investigated.

2.5.1. *Rehabilitation impact on socio-economic costs*

Very little quantitative information is available on the direct and indirect costs of wastewater network failures. Information is also scarce and scattered on social costs of rehabilitation works (Werey et al., 2004).

CARE-S helps addressing the socio-economic ("indirect" or "external") costs linked to rehabilitation decision: impacts of failures and impacts of rehabilitation works to third parties. The definition of "social costs" considered by the project is: "The costs incurred by society as a result of sewerage works or of sewer failures, and for which utilities or companies have no direct responsibility apart from possible compensation". The operational objective of this is to provide guidance and methods for assessing criteria for rehab planning representing social costs. This can be divided in two parts:

The first deals with criteria on external socio-economic impacts of rehabilitation works for comparing a limited set of technologies when considering a given single pipe. The technologies are described through outputs of the rehab technology information system. It provides criteria exclusively for selection of technology to specific projects.

The second deals with criteria on external socio-economic impacts of network failures for comparing various rehabilitation projects, defined each at pipe level. The failures or potential reduction of failure risks thanks to rehabilitation are related to each single pipe (the criteria have to consider the impacts at this scale), and are described through results of the structural condition and hydraulic performance modules.

This task includes the definition of a conceptual framework accounting for the links between technical, economic and social aspects, as well as an analysis of social accompanying tasks linked to failures and works (management of claims). It is based on both synthesis of literature (methods, results of studies) and analysis of real world data (claims, compensations, failure events).

2.5.2. *Rehabilitation impacts on social quality of life*

Based on various investigations including population and shop-keepers surveys, the perception of impacts of works and from failures have been analysed, together with the relationships between the public and the utilities (Sousa de Silva et al, 2005).

2.5.3. *Public acceptance of rehabilitation and communication with public*

Based on feedback from field investigations, best practise and guidance are proposed for communication with the public, under circumstances of rehabilitation works or of failures (Barbier et al., 2005).

2.6. MULTI-CRITERIA DECISION SUPPORT

The objective of multi-criteria methodologies in CARE-S is to provide decision support for three different types of decisions, namely developing a long-term rehab technology, selecting cost-efficient rehabilitation projects and choosing the best rehabilitation technology. Different procedures of multi-criteria decision support are analysed, that have been applied in the part to decision support in the field of infrastructure rehabilitation.

2.6.1. *Developing long-term rehabilitation programmes and strategies*

Long-term rehabilitation programmes and strategies have to be developed on the basis of condition forecast of the local network. In CARE-S this is done with the tool GompitZ (LeGat 2004). Transition functions from the one into the next poorer condition class are empirically derived from a sample of inspected sewer pipes. The transition probabilities are used to forecast the future condition of sewers. The most probable date of entering a critical class can be forecast from pipe characteristics, such as material, period of construction, location, use for waste and/or storm water, profile, diameter and so on.

2.6.2. *Ranking and selecting rehabilitation projects*

The total costs of all viable rehabilitation projects usually exceed the available budget. So the projects must be ranked by efficiency criteria in order to spend the money on those projects promising the most positive effects. The objective of this routine is therefore to select and rank a finite number of rehabilitation projects. The method is based on an elimination principle, consisting of three elementary steps:

1. Setting a threshold value for elimination of project candidates at a specific criterion
2. Observing the consequences of the elimination step at all other criteria
3. Confirming or rejecting the elimination threshold and setting the next threshold at the next criterion

The process is repeated until a break-off limit (for example a given budget) is reached.

2.6.3. *Choosing the right rehabilitation technology*

The right/best sewer rehabilitation technique, in economic as well as technical terms, is chosen from a set of candidates fulfilling the requirements under specific local conditions. Direct rehab costs are systematically analysed and documented for a variety of open trenching and no dig rehabilitation technologies. Beyond these direct costs, the support system takes into account a multitude of other factors, which are usually collected by wastewater companies preparing a public tender on a specific rehab project. Although from a financial viewpoint, the waste water company would choose the lowest bid, it has also to consider external costs that are not charged directly to the waste water company, such as increased operating costs and travel times for road users (Baur et al, 2003).

Information on the new technologies is coming from the catalogue of rehab technologies, including more than 60 currently available rehabilitation technologies for repair, renovation and replacement.

2.7. WASTEWATER NETWORK REHABILITATION MANAGER

The wastewater network rehabilitation manager is a procedure for integrating the CARE-S tools into a cohesive rehabilitation planning package. The procedure is based on the integrated approach for rehabilitation planning described in EN752-5 and allows rehabilitation engineers to use the tools most appropriate to their planning needs and data availability (Hulance et al, 2003, 2004).

The CARE-S Manager has been presented in a report with the following content:

1. *A Generic Rehabilitation Planning Process*: a description of the general process that would be carried out when planning the rehabilitation of wastewater networks, regardless of the analysis tools available to the

rehabilitation engineer. This set the scene for how the CARE-S procedure will improve the planning process.

2. *Applying CARE-S to Rehabilitation Planning*: a description of how the CARE-S procedure may be applied to the generic rehabilitation planning process. This has included the identification and definition of methods or software tools which can be used under the CARE-S "umbrella" to develop rehabilitation plans.

2.7.1. *User interface for the Rehabilitation Manager*

The user interface can be defined as any element of the Rehabilitation Manager with which the user will interact. This would include a number of functions, such as:

- importing and manipulating data;
- accessing tools;
- editing data;
- displaying data and reporting the results of analysis, and;
- interactive guidance.

2.7.2. *CARE-S Rehabilitation Manager.*

The rehab manager software consists of a central MS Access 2000 (Visual Basic 6.0) database application with the following attributes:

- It provides a central storage area and reference point for essential CARE-S data;
- It accepts user-validated input data in a pre-defined format. Data source fields will be mapped to fields within the CARE-S database according to the specification of the declared input data source;
- It provides automatic conversion of data item units to standard CARE-S convention;
- It allows user interaction with a pre-determined range of tools under the CARE-S umbrella.

Acknowledgement

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APPLICATION OF DECISION SUPPORT SYSTEM FOR SEWER NETWORK REHABILITATION

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Abstract. Efficient planning requires the planner to be in possession of a substantial amount of background knowledge and experience on the types of encountered problems, current performance and possible effective solutions. The engineer must be aware of the objectives of rehabilitation for each problem, and apply sound judgement using all the tools available in an appropriate manner. This places huge demands on the engineer when many rehabilitation methods are feasible and there are many solutions to improve service delivery to customers (a multivariate problem). The engineer must be guided by a suite of useful analysis tools to help him choose the most cost-effective rehabilitation options.

Keywords: decision support system; rehabilitation planning; sewer system; urban drainage.

1. Introduction

CARE-S - Computed Aided Rehabilitation of Sewer Networks is a project funded by the 5th EU Framework Programme. It started in October 2002 and finished in September 2005.

This project deals with public sewer and storm water networks of any dimension. It includes problems caused by ageing, structural failures,

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inflow/infiltration, exfiltration (leaking) and insufficient capacity which can cause floods, pollution of receiving waters, pollution of ground water and soil, treatment plant impacts and increasing maintenance costs (Sægrov et al., 2005).

It shows that the present policies of rehabilitation in water and wastewater services are based on “reactive approach”, i.e. fixing of acute problems. Within CARE-S the decision support system using “proactive approach” was developed - motto: *“Rehabilitate the right sewer at the right time by using the right rehabilitation technique at a minimum total cost, before serious failures occur.”*

Firstly, there is an objective definition of working with CARE-S:

- Introducing of a new software,
- Function testing,
- CARE-S application on the real sewer network in the conditions of the Czech Republic.

2. CARE-S Rehab Manager

CARE-S Rehab Manager is a computer programme consisting of a set of tools, which allows their communication and data transfer. These tools deal with different sewer system maintenance aspects in order to describe current and forecast future system conditions. The Rehab Manager interacts with the user via a sensitive (understandable) user interface (input/output files, GIS, tables, dialog windows, graphs, printing results). The software consists of an MS “Access 2000” database application, written in Visual Basic 6.0 (Hulance et al., 2003).

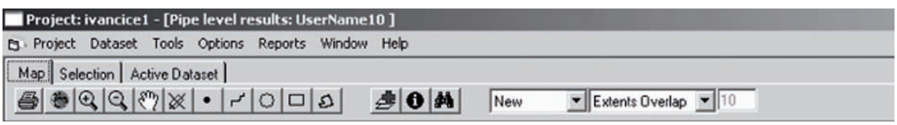

Figure 1 CARE-S menu options and toolbar

3. CARE-S Tools

CARE-S software package includes 18 various interconnected tools. The pages below describe their brief characteristic in compliance with the aspects they address.

3.1. PERFORMANCE INDICATORS

3.1.1. *PI Tool/S (Performance Indicator tool)*

Performance Indicators (PIs) may be considered as providing key information needed to define the efficiency and effectiveness of the delivery of services by an undertaking (Matos et al., 2003). A performance indicator may thus be used as a quantitative (or in some cases qualitative) measure of a particular aspect of an undertaking's performance or a standard of service. PIs may be used to compare performance historically, or against some pre-defined target. PIs may be used by a wide range of stakeholders in evaluating the performance of the undertaking, including internal evaluation within the undertaking itself.

3.2. DESCRIPTION AND VALIDATION OF THE STRUCTURAL CONDITION

3.2.1. *CCTV Conversion programme*

The structural analysis of sewers is usually based on the results of a CCTV inspection. In Europe, there are several systems currently being used for the classification of specific data from such investigations. The tool converts CCTV files from national coding systems into the CEN coding system (Knolmar and Szabo, 2003).

3.2.2. *GompitZ*

This GompitZ model defines the relationship between the current state and the expected service time of the sewer systems using CCTV classification input. The model is based on an empirical and statistical analysis of the asset data as well as physical functions so as to define the future conditions states, while taking one or more state variables into account.

3.2.3. *Infiltration/Exfiltration model*

Defects in the wastewater sewer fabric (at joints and on the pipe walls) enable exfiltration of wastewater to the surrounding soil as well as infiltration of groundwater when the pipeline is below the groundwater level. Both these consequences are undesirable as they hinder the overall efficiency of the wastewater systems by contributing to the pollution of groundwater and by reducing the efficiency of treatment plants.

3.2.4. *Blockage model*

The Blockage Tool helps the user to assess the probability of sewer blockages and root penetration. The tool is a factorial-based model where the factors are identified by a statistical analysis of historical blockage data, calibrated for each user, and it is to be run on all pipes in the network as an automatic routine.

3.2.5. *Z internal corrosion model*

The Z-model has been developed for rough estimation of the risk of hydrogen sulfide-related problems in sewer systems. It is valid for gravity sewers only.

3.2.6. *WATS (Wastewater Aerobic/anaerobic Transformations in Sewers)*

The WATS model is a two-phase model (including wastewater and sewer atmosphere) addressing a number of coupled differential equations describing processes in the wastewater phase as well as in the gas phase inside the sewer, including both transport and transformations. It simulates microbial and chemical transformation processes of organic matter, oxygen, and sulfurous compounds.

3.2.7. *ExtCorr*

ExtCorr is a computer programme that calculates external corrosion with respect to concrete pipes.

3.2.8. *Load Model*

The Load Model is a computer programme for gravity sewer pipes that calculates stress values in rigid non-reinforced concrete pipes based on external loads and pipe characteristics. The relation between the load and resistance results in a security factor that is consequently translated into risk factor of structural failure. Nomenclature and calculation methods used in this model are based on the European standard CEN EN 1295-1.

3.3. DESCRIPTION AND VALIDATION OF HYDRAULIC PERFORMANCE

3.3.1. *Degradation Tool (Obstacle)*

The Degradation tool is a software tool translating failures effects in parameters values producing the same hydraulic conditions caused by failures. In pipes where CCTV inspections detect failures, their hydraulic effects are calculated using the degradation tool. The tool provides new hydraulic parameters (recalculated Manning or lambda or local headloss coefficients) for each degraded pipe.

3.3.2. *GAT (Ground water Assessment Tool)*

GAT is software assessing the vulnerability of groundwater due to exfiltration from sewers. GAT is based on the rating methods and allows for the identification of areas that are sensitive to groundwater pollution caused by exfiltration from sewers.

3.3.3. *CAT (Combined sewer overflow Assessment Tool)*

CAT is a software tool assessing the performance of combined sewer overflows (Schulz and Krebs, 2004). The tool compares the results of hydraulic simulations to user defined standard values over a given number of years. The number, volume, load and duration of combined sewer overflows (CSO) can be evaluated. The assessment is based on the national legislation.

3.3.4. *Hellmud Tool (Hydraulic and Environmental reLiabiLity Model of Urban Drainage)*

The mathematical model is focused on service reliability, which reflects the probability of hydraulic efficiency and environmental impacts of the sewer system for one predetermined scenario (Hlavinek et al., 2005a). The model aims at a definition of several criteria that can be used for the assessment of the reliability aspects of the current sewer system or for the examination of proposed scenarios of the urban drainage system rehabilitation.

3.4. SOCIOECONOMIC TOOLS

3.4.1. *Cost Tool*

One of the most important criteria when choosing a technique is obviously its direct costs. Unfortunately, this also becomes the most difficult task. The difficulties originate from the fact that each sewer work is different: the working conditions change, the suppliers and the general construction costs may differ depending on the regions and time. Thus it is clear that the aim of assessing the direct cost for rehabilitation technologies is to provide a tool for guidance and comparison purposes only.

3.4.2. *Socio-fail Tool, Socio-works Tool*

“Socio-fail/Socio-works” is an Excel® sheet based software, part of the CARE-S decision support system, which is meant to prepare criteria related to the socio-economic costs of sewer pipes failures/rehabilitation works (Werey et al., 2004). These criteria are used by the CARE-S multi-criteria procedure, which helps prioritise the pipes for rehabilitation (SRP Tool).

The software user has the possibility of validating or changing all data related to the environment of the pipe, as well as any criteria value. The user can choose the criteria values according to his needs, and to take into account his local knowledge of socio-economic costs due to the sewer failures/rehabilitation works.

3.5. MULTI-CRITERIA DECISION SUPPORT

3.5.1. *SRS (Selection of Priority Solution)*

The projection of the future condition provides two advantages for active management. The necessary capital costs may be set for various rehabilitation strategies characterised by a fixed budget, minimum required condition of the network or other performance indicators that can be forecast. Secondly, the results of inspections of the individual pipes may be used when planning further investigations, as well as for calculations of the future costs of the sewer system operation.

3.5.2. *SRP (Selection of Priority Project)*

CARE-S SRP is a computer programme that supports the selection of the most efficient pipes for rehabilitation within a network. It employs an interactive elimination procedure to select those pipes with such characteristics or criteria values that indicate that the pipes are not candidates for rehabilitation. Before the elimination of those pipes is confirmed, the effects on other characteristics or criteria are compared with respect to the initial performance of the network.

3.5.3. *SRT (Selection of Rehab Technology)*

CARE-S SRT is a computer programme that supports the choice of the most appropriate rehabilitation technology for a rehab candidate pipe (Baur et al., 2003). It compares the characteristics and performance data available for the rehabilitation technologies within the database (Montero et al., 2004; Hlavinek et al., 2005b) with the information on the condition detected by the CCTV inspection. The catalogue of rehabilitation technologies can be imported from the CARE-S rehab technology database, and it can be modified manually.

4. The Ivancice Catchment Case Study

The Ivancice municipality is located in South Moravia, approximately 30 km south-west of Brno at the confluence of three rivers – the Jihlava, Oslava, Rokytna. There are 7,785 inhabitants living in this municipality.

The sewer system has a total length of 26 km and it is made up of three main sewers A, B, C. It is a prevailingly combined sewer system, the average impermeability coefficient is 0.34, and the average pipe depth is 3 m below the ground level. Pipes cross section is circular (96%), the rest is egg-shaped profiles

Ivancice has a catchment of 162.77 ha, and it can be considered as a residential area. The drainage system includes 732 pipes and 739 manholes, 8 weirs and 5 pumping stations.

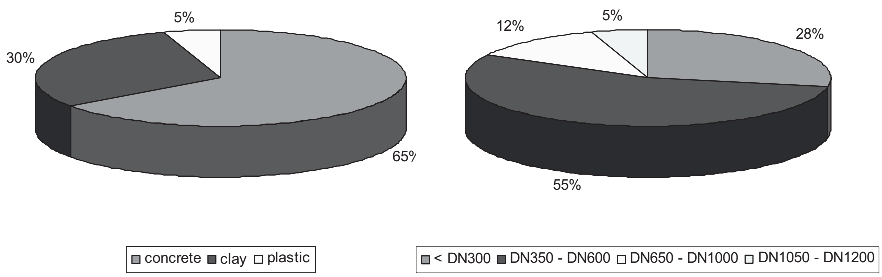

Figure 2 Material and dimension pipe distribution

4.1. DATA AVAILABILITY

This municipality has been chosen for CARE-S prototype testing because of the appropriate size (number of pipes, easy control) and a well developed Master plan (2004), providing a set of complete information. MOUSE is used for hydraulic simulation. The input data has been adequately simplified for testing purposes.

4.1.1. *Data for hydraulic simulation*

A dry weather flow (DWF): A dry weather flow determination has a substantial effect on the calculation accuracy of the combined sewer overflows and consequently on the pollution impact on the river. The Q/H measurement was performed during 06-08/2003.

The synthetic rain events (SE): We used three synthetic design storms (according to Sifald) with a frequency of 1; 0.2; 0.05.

The historical rain data (HRD): There is no measurement of rain events in this area. For testing purposes, a historical rain data from the near catchment was used. HRD consists of 29 worst rain events from the period of 1975-96.

4.1.2. *Additional information*

The istallation year (partly based on resident verbal information); CCTV data (protocols and camera inspection records were provided by the Master plan maker); wall thickness (obtained from the pipe producers and distributors); current roughness (from MOUSE); ground water level and soil type (from a geological-engineering survey); input information for performance indicators (provided by the Master plan maker and the operator of the sewer network); BOD, COD, specific water consumption (derived from the Master plan), etc.

4.2. CARE-S SOFTWARE APPLICATION ON THE REAL NETWORK

- PI Tool/S evaluated 16/41 performance indicators from the period of 2002-2004. The operator should start monitoring new indicators to help better describe the system performance and to gain a better knowledge about long time efficiency.

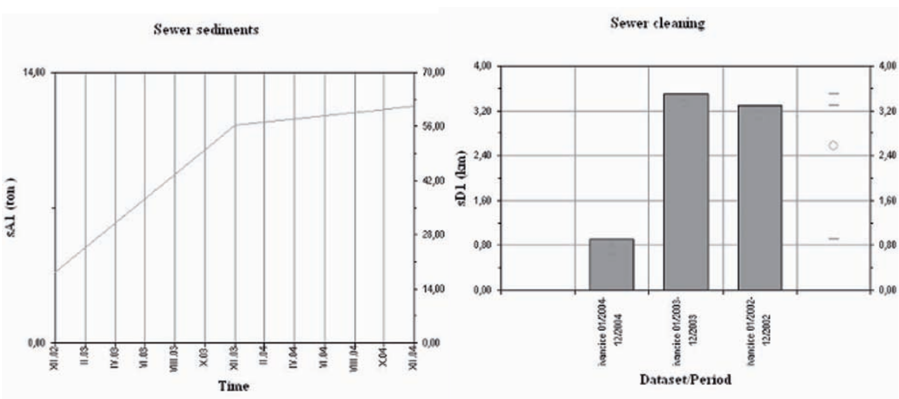

Figure 3 Time series and data set comparison graphs (PI Tool/S)

- CCTVCENConvertor was used only for data uploading to the central database, as the CCTV records were directly recorded to CEN coding.
- There were approximately 160 m inspected pipes. That is why the current condition grades were assessed mainly according to the Master plan (1 – new/rehabilitated pipe, 2 – prospectively for reconstruction, 3 – the worst condition) for running a GompitZ.
- New roughness values were recalculated on the basis of CCTV by a Degradation Tool. They substituted the initial values in the hydraulic model file *.und. The new simulation corresponds better to the current condition of the of sewer.

- An internal corrosion rate was evaluated with a simple Z model, an external corrosion rate was evaluated with a ExtCorr model.
- In our case, the most detailed method of CAT calculation was selected. We used all thresholds and the operator can now easily see how each CSO structure influences the recipient.

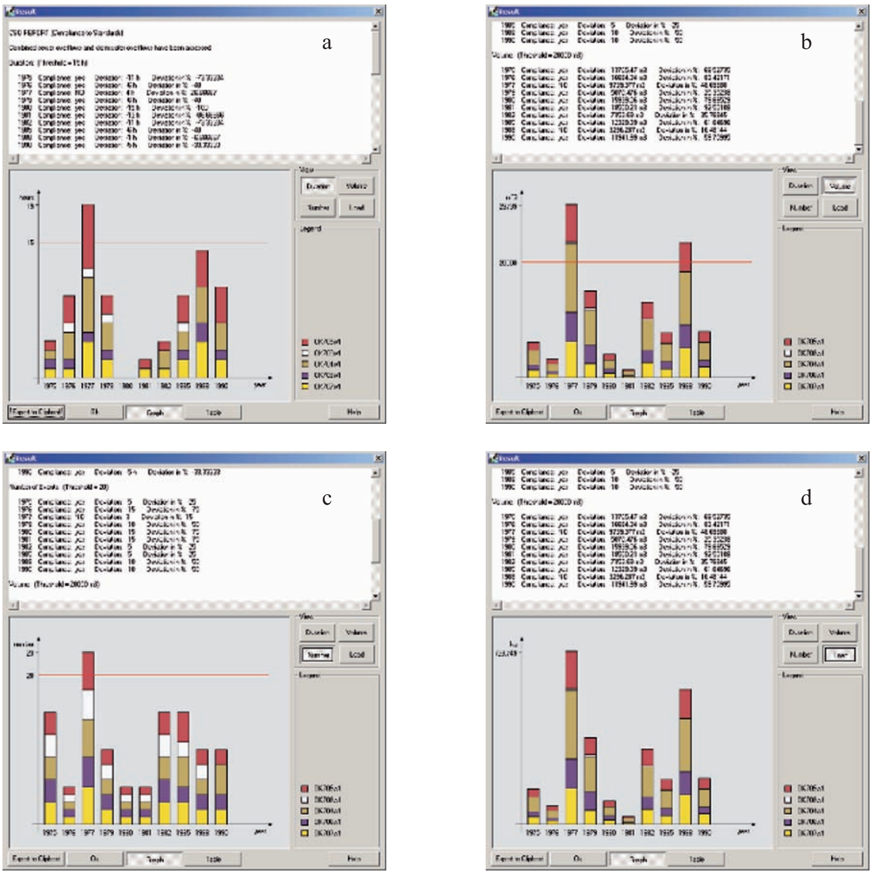

Figure 4 Graphical CAT Tool results: a - Duration of overflows, b - Volume of overflows, c - Number of overflows, d - Load of overflows)

- The vulnerability of ground water was determined by a GAT tool (HML method).
- Hydraulic performance was calculated with a Hellmud Tool. Firstly, a critical wastewater level value was changed (it depends on the location of basements and service connections). The main results are the evaluated

probability of reaching levels (see Figure 5) and correspondence with the velocity criteria in each pipe. The user gains knowledge of the potential hydraulic problem pipes. We compared Hellmud results with the evaluation within the Master plan. The results were very similar, the Hellmud results were more detailed.

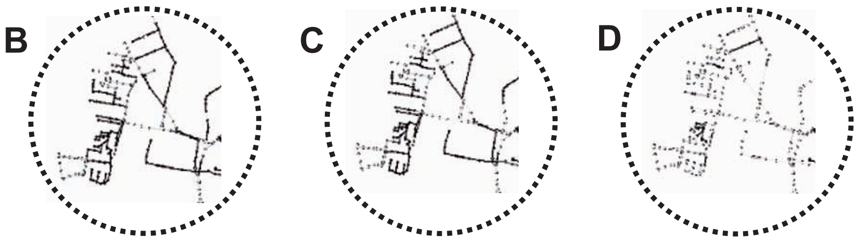

Figure 5 Hellmud SE simulation – Results in GIS (probability of reaching level: B – top of pipe, C – critical level, D – ground level; full line - level reached, dotted line - level did not reached)

- Socioeconomic tools were not used for this municipality because of lack of data. At least rough investigation of socioeconomic indicators and factors influenced by rehabilitation works is recommended.

Following the sewer system evaluation with the assistance of several tools we proceeded to develop a long-term rehabilitation plan. Rehab Manager offers four main strategies related to the future rehabilitation approach (“rehabilitate nothing”, according to “length of pipe rehabilitated”, “budget” or “pipe condition”). The user has to define the time horizon and economic conditions.

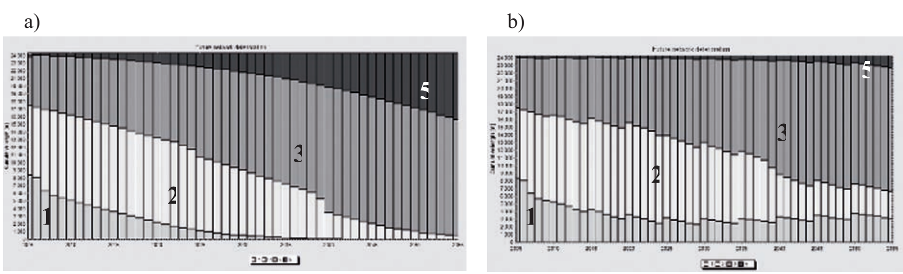

Figure 6 Condition forecast during next 50 years (a - “rehabilitate nothing”, b - “length strategy”)

The example of the ”length strategy” is shown in the Figure 6b. Relation between time in years (x-axis) and length of the pipes of appropriate condition (y-axis) demonstrates development of network degradation in time. Pipe condition “1” (light at the bottom) is the best, “5” (dark at the top) is the worst (condition “4” did not occur within the network).

After assessment of the strategy was proceeded the selection of priority pipes. A candidate group of pipes with the highest priority for rehabilitation was selected on the basis of elimination by means of criteria obtained from previously used CARE-S integrated tools.

A suitable rehabilitation technology (from the rehabilitation database) was assigned (pairwise comparison) to each candidate pipe in dependence on the pipe, failure and environmental information.

5. Conclusion

CARE-S software is an expert system offering four main outputs to the user:

- Sewer system current state assessing,
- Long-term investment needs specification,
- Pipe selection recommended for rehabilitation and
- Proposal of adequate rehabilitation technology.

The users of this product, the CARE-S suite of tools, can be wide range of stakeholders - the owners of waste-water systems, operating companies, financial institutions and national governments. Each of them has individual information requirements. The assets owners or shareholders are interested in maintaining the value of infrastructure and set the standards in a contract with the operator. The operating company needs information on investment needs to maintain the assets with respect to the standard defined in the contract. The financial institutions and potential investors need information on the magnitude and economic viability of rehabilitation investments, and the national governments need the information for decision-making and advising on water prices.

Among the main CARE-S advantages belong especially:

- all sewer system information stored in one database,
- comprehensive rehabilitation technology catalogue,
- sewer system assessing according to different aspects (hydraulic, socioeconomic, pipe condition, environmental impacts, maintenance, etc.)
- comfortable user interface,
- GIS result windows,

- camera inspection planning,
- suitable aid for Master plan making.

It should be noted that the CARE-S software is a tool to help an engineer devise annual and strategic rehabilitation plans; it will assist the engineer in developing a rehabilitation plan based on the integrated analysis of the relevant issues but it does not, (and is not intended to) produce the plan itself. A final decision is up to the user and it depends on the output interpretation and budgets as well as the manager's strategy. Last but not least, the quality of output directly depends on the quality of inputs (GIGO).

We tested the latest developed CARE-S prototype version 2.5.0.0. (2.6.0.0). At the time of preparing this article, the CARE-S project was not completed. The final programme version should be available at the end of 2005.

Acknowledgement

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IMPLEMENTATION OF FIBER OPTIC CABLES IN SEWAGE SYSTEM

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Abstract. Implementation of optical fibers in the cities causes the involving excavations of city streets**.** These excavations cause pollution, traffic hold-ups, economic loss, and unsafe conditions to the inhabitants in every city. Even worse, the repair of the streets after excavation rarely left the streets in acceptable condition. These forced mayors to issue moratoriums on new open cut excavations involved in the "Last-Mile" work. The "Last-Mile" is the section of a network that connects from the basement of an end-user building to the city-area network that surrounds a city. The novel idea of leasing space inside of existing sewers by telecommunications companies has a rather interesting appeal in that owners of existing sewers get to generate a new revenue stream and telecommunication companies could install their optical fiber cables at an attractive cost. This paper describe the advantages of building optical fiber networks inside existing sewers, base conditions for this implementation and briefly describe the interactions between the pipe, cable and liquid. The computer simulations was execute with MOUSE model in the Slovakia.

Keywords: excavation; informatics; optical fibers; pipe; robot; sewer system; trench-less methods of rehabilitation.

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1. Introduction

Many million people are expected to telecommute to work by 2010. This will increase the productivity and quality of life significantly. This will also save energy, reduce pollution, and re-distribute the wealth and real estate values. For this to happen, we need to turn to existing underground infrastructure to build our communication networks, so that we can avoid additional congestion underground. Civil engineers have been responsible for planning, designing, constructing, operating, and maintaining this vast network of pipes below our feet. Civil engineers need to start planning now toward working more closely with telecommunication engineers in making the information age come into full bloom so that any obstacles can be removed with the team approach. This will involve sharing the underground so that the same sewers are used for multiple functions.

The water and telecommunication companies need some government Act in Slovak republic, which would be helpful for interactions between both.

2. Why Retract Fiber Optics Cable into the Sewer?

The idea for multiply uses of the pipes is very old. This reaches the Paris more than 100 years ago, but poor results dispose it. The comeback was in 1983 when Dr. Jeyapalan starts retract the high-voltage cable into the pipes in existing dams. This causes the research laboratory creation, where the simulations of interactions between cable and the liquid in the pipe executed.

In recent years, and still today, many companies are laying optical fiber cable between continents, countries and cities. Even building owners have started laying fiber from their rooftop to basement; however, the missing link is still the last mile. While the entire telecosm is in chaos, everyone in this industry should ask the fundamental question: "where are the on and off ramps to the information superhighway most companies have been building for 2 decades in optical fiber cables?"

Naturally these information superhighways with their limited points of origin with a similar tale at the other end would remain empty with no one willing to pay the toll to the owners of such long haul networks. These limitations result in a mere 10% of the long haul fiber being lit. Given how we humans always take the path of least resistance have avoided bridging the last mile, which would be the hardest and the costliest, without ever realizing that without the ultimate on and off ramps, there would be no use for such long haul routes circling the continents. The so-called fiber glut in the backbone and long haul fiber networks is mostly due to the lack of last mile fiber to provide the final link between the premises and the long haul carriers of data, voice, and video. While the world anticipates becoming a true virtual world, where time and distance could never become factors, the final link has been missing for too long for most of the inhabitants.

3. Rule of Manholes

The sewer manholes form is an important part of this technology due to them serving as major access ports. Junction boxes and extra cable lengths are stored in telecommunication hand holes located in close proximity to the sewer manhole yet away from the main traffic thoroughfares. These hand holes also serve as customer connection points. The initial plan for fiber companies is to target buildings, which meet certain criteria such as minimum floor area, number of tenants, building owners' needs, type of tenants, existing communication services in the area, etc. (Jeyapalan, 2003b). A ring topology is preferred to service the buildings to meet redundancy requirements, optimum bandwidth needs, the tree and branch geometry provided for in the sewer paths, future expansion needs, etc. The splice points on these mini-rings are located off the main traffic route to provide a safe zone for access for customer connections. These dry connections are sealed with mechanical means to ensure that no sewer gas escapes (Jeyapalan, 2001).

4. Sewer Selection Criteria for Optical Fiber Cable Installation

Operating an optical fiber network in the sewers poses its own challenges. Proper civil engineering input is essential for the selection of the suitable sewer system for deployment. The factors to consider in selecting the right sewer path are:

- Access to the Sewer;
- Hydraulics of the Sewer;
- Structural Capacity of the Sewer;
- Sewer Cleaning After Installation of Optical fiber Cable;
- Sewer Inspection After Installation of Optical fiber Cable;
- Sewer Maintenance After Installation of Optical fiber Cable;
- Compatibility of the Sewer Wall;
- Presence of Excessive Grease in the Sewer;
- Presence of Excessive Chemical Reagents in the Sewage;
- Presence of Excessive Calcium Deposits on the Sewer Walls;

- Presence of Joint Separations/Offsets;
- Presence of Excessive Root Intrusion: Condition of the Manholes;
- Condition and Frequency of Lateral Connections.

4.1. ACCESS TO THE SEWER

The primary access to the sewer for fiber cable installation using a robot is through the manholes at both ends of the reach. It is desirable that the length of the reach is shorter than 135 m, so that the umbilical cable needed by the robot for the supply of air, electricity, and communications circuits could extend from one end of the reach to the other. If man-accessible pipes were chosen, then this limitation would not apply.

4.2. HYDRAULICS OF THE SEWER

Although engineers intend not to have any leakage of sewage from the sewers, with aging and inadequate maintenance, most sewers have leaking joints during the design life of the sewer. Given this history of performance, the designers have been able to count on only 85% of the actual flow area to convey the flow, due to a loss of some sewage through leaking joints. An estimate of the flow conditions under the worst possible scenario based on past flow records in that sewer needs to be done before the sewer is considered for optical fiber cable installation. Engineering data used in the evaluation should be based on actual sewer sizes and actual flow conditions rather than those based on original design or as-built drawings. Enough attention needs to be paid to surcharging, slope problems, lack of sewer capacity, and future upsizing of the sewers.

4.3. STRUCTURAL CAPACITY OF THE SEWER

An evaluation of the structural capacity of the sewer to carry the soil load, groundwater load, and live load need to be conducted. This is to ensure that the current condition of the sewer is adequate to house the optical fiber network. The decision whether and when to rehabilitate the sewer if the current condition is found to be questionable need to be carefully taken using all necessary engineering data (Berliner Wasser Betriebe, 1997). If the cost and time duration of rehabilitating the sewer would result in a significant delay and added financial burden to either the sewer owner or the optical fiber network owner, an alternate route for the intended optical fiber mini-ring shall be pursued to ensure that the engineering criteria to be met are not relaxed.

4.4. SEWER CLEANING AFTER INSTALLATION OF OPTICAL FIBER CABLE

Sewers need to be cleaned periodically as part of their maintenance. Once optical fiber cables are installed in the sewer, special precautions must be taken in choosing and applying suitable cleaning methods, which would not cause damage either to the sewer wall or the optical fiber cables.

4.5. PRESENCE OF EXCESSIVE GREASE IN THE SEWER

During the cleaning and inspection process, sufficient grease should be removed to permit inspection of the pipes. Sections of pipe with grease accumulations of over a suitable thickness within one year of cleaning should not be considered candidates for fiber optic system installation until proper remedial action is taken. Remedial action includes tracing source of grease and enacting/enforcing ordnances to require use of grease traps and/or oil separators.

5. Present State in the World

The many cities in the world have the experiences with optical fiber implementation to the sewers. Table 1 shows the lengths of the implementation in the knowing cities.

TABLE 1 List of the cities with the fiber optics network installation (Japan Sewage Works Association, 1997)

	City	km in sewers		City	km in sewers
1.	Tokyo	850	13.	Albuquerque	9
2.	Vienna	400	14.	Osaka	6
3.	Hamburg	100	15.	Toronto	5
4.	Berlin	50	16.	Himeji	5
5.	Yokohama	42	17.	Indianapolis	5
6.	Kawasaki	37	18.	Hanau	5
7.	Ogaki	24	19.	Tokushima	4
8.	Sapporo	21	20.	Munich	3
9.	Nagoya	18	21.	Amsterdam	2
10.	Kyoto	18	22.	Copenhagen	2
11.	Minami	13	23.	Madrid	1
12.	Yodagawa	11	24.	Boston	1

6. The Ways How to Retract the Fiber Optics into the Sewer

There are at least five robot companies, namely: CableRunner, DTI-CableCat, Ka-te (Alcatel, 1998), Nippon Hume, and RCC.

CableRunner uses a drill and dowel system in 7sewers of 250 to 700 mm in size. **DTI-CableCat** uses either a back-reamed anchor or an adhesive bed system in sewers of sizes 200 to 1200 mm, while **Nippon-Hume** (Nippon Hume Corporation-OFI Business Dept., 2001) and **RCC** use drill and dowel systems for the same sized sewers. **Ka-te** uses a clamp-conduit system in sizes smaller than 700 mm. There is a good chance that these liner companies will succeed if they are able to offer value-added relining systems for an attractive incremental fee to the city sewer agencies over the standard lining systems without cutting too much into the current functions of the sewers. Companies TMG, Corning Cable Systems MCSDrain, and Ashimori Industries' offering to use tensioning devices to span the optical fiber cable manhole to manhole to anchor them on the walls of the manhole are quite similar (CityNet Telecommunications, 2000). It is also possible to replace an aging pipe carrying sewage with a new pipe and provide additional smaller sized conduits on the outside of the new pipe for the insertion of optical fiber cables and/or power distribution cables (Jeyapalan, 2003a). If the sewer is larger than 700 mm in size, then many possible ways of using humans to attach the optical fiber cables to the walls of the sewer can be used at a relatively low cost of materials and labor and at high production rates.

The CableRunner was designed, developed and patented by the municipal sewer company of Vienna, Wien Kanal Abwassertechnologien GesmbH (WKA), to use their existing combined sewer system to carry fiber optic cable. The city of Vienna is an old city with narrow streets and historic buildings. With limited space and time constraints, using the existing sewer system was the most viable alternative when expanding their telecommunication capacity. The CableRunner system has also been used extensively throughout other cities in Europe.

7. Rehabilitation of the Sewer and Fiber Optics Retract

There are numerous technologies, which have been in use for some time for rehabilitation of sanitary sewers. These methods could be broadly classified into two types namely: "**trench-less**" and "**less-trench**".

In the **trench-less** methods, the process needs to be applied from one existing manhole to the next one with the laterals needing reconnection using robotic cutters. It is most common not to have any open-cut excavation at all in or around the job site. Examples of such methods are cured-in-place in Place Pipes, Fold and Formed Pipes, Pipes by Directional Drilling, Robotic Repairs, and Fill & Drain Technologies.

In the **less-trench** methods, some excavation is always required. These are used to introduce the new pipe into the system and for reactivating the laterals. Some processes require pits, auger holes, while others need sloping trenches leading into the old pipe. Few examples are Slip-linings, Swaged & Rolled Down Pipes, Spiral Wound Pipes, Segmented Linings, Pipe Bursting, Micro-tunneling, and Pipe Ramming.

But this sewer mainline renovation market has matured and has gone through a major shake out leaving only a few profitable players to move forward into the next decade. For example, in CIPP and Fold and Form methods, the winner is decided primarily based on price and the advantage goes to those who hold the volumes when it comes to having the ability to get discounts on liners and resins. Those smaller contractors who are focused and are local players also are able to stay in business given that they do not have to send a slice of the pie toward corporate overhead.

8. Influence of Implementation Fiber Optics to the Sewer – Calculation by Simulation

The some research concerning the lower capacity of installation the optical fiber cables into the sewer were realized in the Department of Sanitary & Environmental Engineering, Faculty of Civil Engineering, Slovak University of Technology. The main idea was to recalculate the capacity of the sewers with many various systems of optical fiber retractions. Basic conditions were: minimal slope of the sewer, the diameter of the sewer, the geometry of the sewer. We used the hydro-dynamics model MOUSE fy DHI, which allowed to define the cross section of the profile with the optical cable Fig 1., Fig 2.

The results of the simulation shows, that the installation of the optical cable has no bad influence on the discharge.

Simulation was executed using 3 systems: Ka-Te, Nippon-Hume and Cabotics.

TABLE 2 Comparison of results discharges [l/s] computed in various systems

DN[mm]	300	400	500	600	800
Circular shape	54,9	103,7	167,4	248,7	466,9
Ca-Botics system	53,23	106,0	174,6	263,12	483,71
Ka-Te system	49,41	100,54	168,41	253,4	486,79
Nippon Hume system	53,8	114,3	192,35	294,71	574,35

TABLE 3 Comparison of results discharges [in %] computed in various systems

DN[mm]	300	400	500	600	800
Circular shape	100	100	100	100	100
Ca-Botics system	-3,04	+2,22	+4,3	+5,8	+3,6
Ka-Te system	-10,00	-3,05	+0,6	+1,89	+4,26
Nippon Hume system	-16,46	-6,16	-3,1	-0,2	+4,2

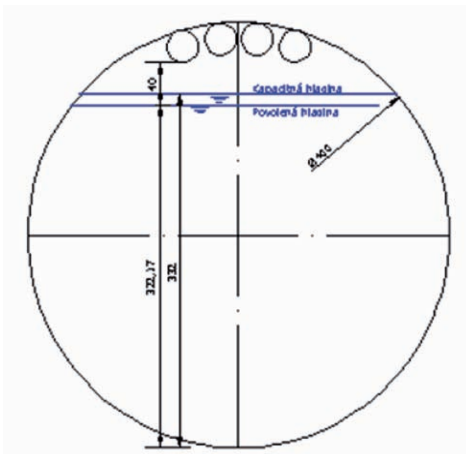

Figure 1 Example of sewer geometry Ka-Te system

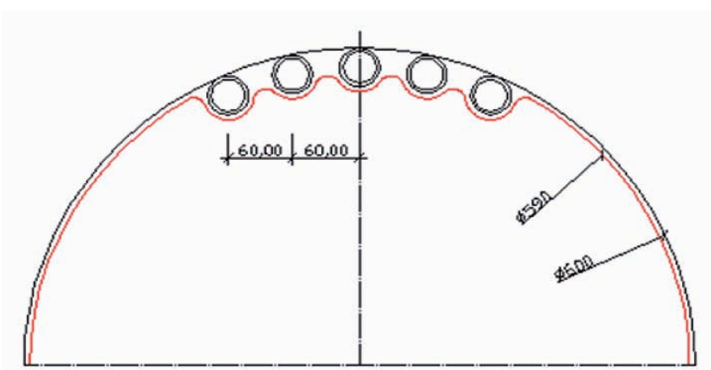

Figure 2 Example of sewer geometry with optical fiber cable - Nippon Hume

9. Possibilities in Slovakia

The best-one conditions for implementation optical fiber cables in sewer system give the big cities. We could use the very simple formula: the big cities with high density of population generate best-one conditions for optical fibers into the sewers, because quick cost-investment return is secure. The Slovak state of sewerages is in very poor quality, so these expect rehabilitation, which is the advantage for implementation.

The capitol of Slovakia – Bratislava offers good conditions for optical fibers implementation. The 679 km of sewers need 208 km (30.6%) rehabilitation 132,5 km are sewers from concrete; 41,4 from reinforced concrete; 34,1 km stoneware.

Present state in Slovak republic is very poor, because the agreement between water companies, which are in holding transformation, and the telecommunication companies doesn't exist. Although the effective of installation was proved, installation of optical fibers makes in own excavations, not sewer implementation.

10. Conclusion

The installation of optical fiber cables inside of sewers is a major break through in sharing the underground space to form utility corridors. Telecommunication companies need to address all the concerns associated with using existing pipes, before wide spread fiber deployment could proceed. Those in this business should recognize that the trench-less pipeline renovation business has matured significantly in the past 10 years. City officials, engineers, the public, and business owners all want the least disruption and inconvenience possible.

The first mover advantage is there for certain companies. Once established as a leader, the odds are in favor for that company staying the leader. This is true provided the management of that company is nimble, is re-inventing itself with changing times and is continuing to add the best talent available in its workforce.

The factors which will continue to provide momentum for the market are:

- Aging underground infrastructure
- Doing more work with less funds
- Protecting the environment
- Increasing congestion in urban and suburban centers
- Faster rate of technology transfer and information
- Privatization of utility companies

More emphasis will be placed on evaluating the current condition of the entire pipeline network for cost effective spot maintenance and renovation strategies.

Not all sewers are amenable for installing optical fiber cables and companies which support strong engineering talent on their staff will focus their attention to those lines which would satisfy proper engineering criteria.

The deployment of optical fiber cables in existing pipelines offers a win-win situation for all parties involved if proper standard of care is afforded. However, working in sewers requires sound pipeline engineering input and anything less than that would be shortsighted. If telecommunication companies did not follow proper engineering know-how, it would only be a matter of time before we will face major problems and the cost to return these sewers and gas lines to normal working order would be far greater than the lease revenue fiber installers are offering at the present time.

Acknowledgement

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OVERVIEW OF URBAN DRAINAGE IMPACTS ON AQUATIC HABITAT

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Abstract. Urban drainage impacts on aquatic habitat are discussed under five major headings affecting the biological community performance: food (energy) sources, water quality, habitat structure, flow regime, and biotic interactions. Among these factors, perhaps the best understood one is stormwater quality. On the other hand, the changes in the (physical) aquatic habitat structure resulting from urbanization and stormwater discharges are the least understood and require further study. Promising approaches to mitigating the adverse drainage impacts on habitat include preservation of natural drainage features, sustainable development or redevelopment of urban areas, and balanced applications of stormwater management practices.

Keywords: flow regime; habitat structure; stormwater management; stormwater quality; urbanization; urban stormwater.

1. Introduction

Urbanization causes profound impacts on the hydrological cycle, with many implications for aquatic habitat (Horner et al., 1994). When discussing the impacts of urban drainage on aquatic habitats, one can follow a general list of factors influencing the biological community performance, including food (energy) sources, water quality (chemical variables), habitat structure, flow regime, and biotic interactions (Yoder, 1989). Urbanization even at a low level

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of development (10% of the watershed area) exerts effects on receiving waters and thereby directly or indirectly affects the habitat (Horner et al., 1994). Thus, one of the main tasks of urban environmental planners and managers is to reduce such effects (Schueler, 1987).

The main purpose of this paper is to review the effects of urban drainage and stormwater management on aquatic habitat in urban streams.

2. Food (energy) Sources

Sufficient supply of energy (food) is a basic requirement of all organisms in order to grow and reproduce (Spence et al., 1996). Concerning this requirement, the conditions in the receiving waters should be such that food resources available are comparable to those found in natural waters. Spence et al. (1996) suggest that this requires maintaining a corresponding level of primary production, physical and chemical conditions, and the original riparian vegetation. In this connection, the value of riparian vegetation in providing fish food is particularly emphasized. Standing riparian vegetation is habitat for insects that serve as food source for fish and this vegetation also provides another source of food to aquatic biota in the form of leaf litter. Thus, changes in riparian vegetation, such as elimination or changes of species, will affect the type and abundance of food available to the invertebrate and fish communities. In view of the incomplete understanding of various food sources and their effects on aquatic biological communities, a precautionary approach of maintaining the pre-development water body conditions, is recommended (Spence et al. 1996).

3. Water Quality

Good quality of water bodies inhabited by fish and other biological communities is a basic prerequisite of habitat integrity (Bishop et al., 2000). In terms of constituents of interest, their list includes suspended solids, dissolved oxygen, nutrients, trace metals, organic chemicals occurring at toxic levels, pH and water temperature. Large changes in constituent availability and concentrations may impair the performance of biological communities. Extensive data on urban stormwater chemistry are available in the literature and can be readily used in assessing potential impacts on aquatic communities.

3.1. SUSPENDED SOLIDS

Suspended solids comprise both inorganic (fine sediment) and organic phytoplankton) particulate kept in suspension by flow or turbulence in water. Suspended solids concentrations are particularly high in urbanizing catchments suffering from soil erosion and cause many adverse impacts on receiving waters and their aquatic habitats.

Soil erosion is intensified in urbanizing areas by the stripping of natural protective vegetative covers from the soil surface during construction and by increased runoff flows, which scour unlined drainage channels and transport of eroded material to downstream areas (Horner et al., 1994). Wolman and Schick (1962) reported sediment yields from natural catchments as low as 100 $t/km^2/yr$, but increasing more than 100 times during urbanization. After completion of the urban development, establishment and consolidation of surface covers, the sediment yields drop to the predevelopment, or even lower values. Serious ecological damages are caused by excessive erosion, in the form of sweeping away habitats, expanding stream channel width and depth (Booth, 1990; Urbonas and Benik, 1995); undercutting banks and damaging riparian vegetation, and losing protective qualities of large woody debris (Horner et al., 1994).

Suspended solids cause a number of direct and indirect environmental impacts, including those associated with:

- Reduced sunlight penetration (interference with photosynthesis, reduced abundance of periphyton and phytoplankton, reduced algal productivity, changes in plant communities; reduced visibility for catching food and avoiding predators);
- Physical abrasion of gills and other sensitive tissues, or grinding and dislodgement of algae; damage of aquatic vertebrates and invertebrates;
- Blanketing of gravel substrates where fish spawn, rear their young, and where algal and invertebrate food sources live; filling up of pools where fish feed, take refuge from predators and rest; burial of benthic organisms which will die by lack of oxygen; reducing interstitial space, where invertebrates may live; reduced access to microhabitats; reduced density of benthic invertebrates; and,
- Transport of various pollutants (improving water quality if adsorbing pollutants from the water column and transporting them away; or downgrading water quality if bringing pollutants in from other sources).

Such impacts can manifest themselves at various time scales; a single large rainfall/runoff event can cause significant impacts, but generally long term impacts are more important.

3.2. DISSOLVED OXYGEN

Dissolved oxygen (DO) is important for aquatic life and plants (depending on some minimum DO levels), stream capacity to assimilate waste, and the processes at the bottom sediment/water column interface. The precise definition of harmful (low) DO levels is under discussion, but minimum levels for cold-water biota are usually specified as 9.5 mg DO/L in the early stages of life and 6 mg/L for warm-water biota (Makepeace et al. 1995). DO levels in natural streams are generally high, unless there are large quantities of organic debris, discharges of sewage effluents, and high ambient water temperatures. Low DO levels may occur in shallow streams or stormwater ponds in summer months, when water reaches high temperatures and there is rapid decomposition of organics, or during the winter months, when the stream or pond is ice covered (Marsalek et al., 2003). Water bodies rely on vertical mixing for transport of oxygen to the bottom layers. Such processes are impaired by densimetric stratification of ponds and lakes, particularly in the case of chemostratification by chloride from winter road maintenance. Increased meromictic stability of such bodies reduces vertical mixing and oxygenation of bottom layers (Marsalek et al., 2003).

3.3. NUTRIENTS

Nitrogen and phosphorus are two most important constituents affecting the productivity of aquatic systems. Both may originate from natural sources, but the main concerns are caused by nutrients originating in sewage effluents, industrial discharges, and agricultural and urban runoff. Both N and P occur in various species, which have different implications with respect to toxicity or eutrophication. Some N forms are toxic to fish (e.g., nitrite nitrogen, which is short-lived in natural waters; or ammonia, at concentrations as low as 0.080 mg/L, depending on pH and DO), others, like nitrate, NO_3-N, are essentially non-toxic to aquatic vertebrates and invertebrates (Spence et al., 1996), but may contribute to eutrophication. Phosphorus occurs naturally in very low concentrations, most frequently as phosphates. Such levels are considered non-toxic to aquatic vertebrates and invertebrates, but may contribute to eutrophication.

Nutrient loadings in stormwater may cause nutrient enrichment or eutrophication of receiving waters characterized by an overall increase of aquatic macrophytes and algal biomass, and changes in the composition of algal community from one-celled diatoms to filamentous green forms, followed by blue-green forms. Eutrophication degrades ecosystems in a number of ways, including reduced food supplies, water clarity, dissolved oxygen. The prevention of urban lake or reservoir eutrophication usually requires control of nutrient sources, including stormwater (Schueler, 1987). Typical concentrations of N and P in urban stormwater and CSOs are listed in Table 1.

TABLE 1 Quality of urban stormwater (after Duncan (1999) and U.S. EPA (1983))

Chemical Constituent	Units	Urban Stormwater	
		Mean of Duncan's dataset	U.S. NURP Median site
Total Suspended Solids (TSS)	Mg/L	150	100
Total Phosphorus	Mg/L	0.35	0.33
Total Nitrogen	Mg/L	2.6	-
Chemical Oxygen Demand, COD	Mg/L	80	65
Biochemical Oxygen Demand, BOD	Mg/L	14	9
Oil and Grease	Mg/L	8.7	-
Total Lead (Pb)	Mg/L	0.140	0.144
Total Zinc (Zn)	Mg/L	0.240	0.160
Total Copper (Cu)	Mg/L	0.050	0.034
Faecal Coliforms	#/100 mL	8,000	-

3.4. TOXIC CHEMICALS

In urban receiving waters, toxic impacts may be caused by elevated concentrations of ammonia, chlorides, heavy metals, and trace organic contaminants. The understanding of stormwater toxicity is still incomplete.

Toxicity bioassays applied to stormwater samples from various sources indicated (Marsalek et al. 1999) that about two fifths of all data did not show any toxic responses, one fifth indicated severe toxicity, one fifth confirmed toxicity, and one fifth potential toxicity. Almost 20% of highway samples were severely toxic compared to 1% of general stormwater samples. Stormwater ponds contributed to toxicity reduction, with respect to both water and sediment downstream of ponds. The sources of toxicity in stormwater were identified as heavy metals, Cu, Pb, Zn and Fe, ammonia and pesticides (Hall and Anderson, 1988; Dutka et al. 1994). Toxicity testing was found useful for screening and assessing potential receiving water impacts, but was limited by the dynamic nature and large variety of wet-weather pollution sources (Marsalek et al. 1999).

3.5. PH VALUES

In the urban environment, rainwater is slightly acidic due to both natural and anthropogenic sources of acidity. Concrete structures (street gutters, sidewalks) contribute to rainwater buffering, with runoff pH being neutral. Fish may be adversely affected at pH ≤ 5.6, however, the actual response is species specific and also depends on water quality conditions. Low pH associated with snowmelt and presence of salt may increase the mobility and bioavailability of metals (Novotny et al. 1998). High pH values, originating from pollution, or geology or algae photosynthesis, may also impact fish.

3.6. WATER TEMPERATURE

Sources of waste heat in urban areas contribute to increased temperatures of surface runoff, particularly during the summer months. Stormwater running off hot impervious surfaces (pavements, roofs) collects heat and its temperature may further increase as a result of exposure to solar radiation in stormwater ponds and wetlands (Van Buren et al., 2000). Schueler (1987) reported that stormwater runoff temperatures may exceed those in the receiving waters by up to 10° C. Thermal impacts of heated runoff are particularly noticeable during low flows in receiving streams. Spence et al. (1996) listed some of the physiological (for salmonid fish) and ecological processes affected by temperature as: (a) decomposition rate of organic materials, (b) metabolism of aquatic organisms, (c) food requirements, appetite and digestion rates, (d) growth rate of fish, (e) developmental rates of embryos and alevins, (f) timing of life-stage events, including adult migrations, fry emergence, and smoltification, (g) competitor and predator-prey interactions, (h) disease-host and parasite-host relationships, and (i) development rate and life history of aquatic invertebrates.

Thermal enhancement of receiving waters may lead to succession of the original cold-water fishery by warm-water fishery, and similarly, cold water invertebrates may be similarly impacted and cold-water algae species (mainly diatoms) be succeeded by warm-water filamentous green and blue-green species (Galli cited in Schueler, 1987). Higher water temperatures also lead to reduced concentrations of dissolved oxygen. Increased rates of decomposition of organic materials and reduced DO in heated water may result in oxygen deficiency.

4. Habitat Structure

The physical habitat structure represents the macrohabitat and microhabitat features found in streams, rivers, impoundments, lakes and estuaries. In streams, these features are usually referred to as channel morphology, which can be described by numerous parameters, including channel width to depth ratio, slope (gradient), substrate composition and roughness, bed forms, and sinuosity. Lake morphology is characterized by lake surface area, depth, volume, length, width and shoreline development (shape). Geomorphic properties of the drainage basin are characterized by such parameters as length, relief, relief ratio, basin surface storage, drainage density, drainage shape, main channel slope, and total stream length (Bain and Stevenson, 1999).

Macrohabitat features are generally described by sequences of pools and riffles, and can be further classified as fast water and slow water macrohabitats. Fast water macrohabitat is characterized by such features as low gradient stream sections or riffles, high gradient sections with rapids, steep gradient or cascade, falls, steps, chutes, glides etc. Slow water macrohabitats include pools, straight scours, backwater eddy, plunge, and dammed and abandoned channels. Generally, the sequences and frequency of occurrence of macrohabitat structure are important for habitat quality. Discrete habitats are also called channel geomorphic units and can be described by bed forms, water velocity, and the presence of flow control structures (Bain and Stevenson,1999).

Microhabitat characteristics include substrate type, cover, depth, hydraulic complexity and current velocity (Spence et al., 1996). Substrate is generally classified according to the element or particle size, ranging from silt and clay (< 0.059 mm), to sand, gravel, pebble, cobble and boulders (> 256 mm). Besides the substrate size, embeddedness rating is also important and ranges from negligible (less than 5% of gravel, pebble, cobble and boulder particles surface covered by fine sediment (D< 2mm) to very high, when > 75% of surface is covered by fine sediment.

Cover provides refuge for fish from predators and adverse physical conditions, and can be provided by boulders, large wooded debris, aquatic vegetation, water turbulence and depth. Streambanks and shore provide transition between aquatic and terrestrial ecosystems, and refuge for fish, if in good condition. Such a condition can be degraded by both natural and human impacts, which reduce bank vegetation, erosion resistance, and structural stability. Bank condition is assessed by assessing its geometry, substrate and soil composition, and riparian vegetation.

Low to intermediate barriers, 1 to 10 m high, are fairly common in urban areas. Barriers obstruct fish life cycle (e.g., migration), flow, sediment transport and thermal regime. The degree of disruption depends on the structure height.

Studies of natural fish habitats produced descriptions of habitat requirements for various salmonid species and life stages. It is of interest to note that such conditions widely vary and their reproduction in urban streams is practically impossible (Horner et al., 1994).

5. Flow Regime

Flow regime represents a full spectrum of flow conditions in a particular stream section and reflects the hydrologic cycle. With respect to aquatic habitat, flows of all magnitudes are of interest, because: (i) high flows form the stream geomorphology, cause erosion, transport sediment and affect fish migrations, spawning, and juvenile rearing (Horner et al., 1994), (ii) intermediate flows also contribute to erosion and geomorphology formation, and (iii) low flows may be associate with poor water quality.(e.g., low DO, high temperature) or even discontinuity of flows.

Urbanization is known to affect significantly the hydrological cycle, by reducing infiltration and evapotranspiration, increasing surface runoff flows and volumes, and reducing groundwater recharge. Field observations confirm this behaviour, certainly in smaller streams, which are more impacted by urbanization. Higher flows may cause flooding, sediment and habitat washout (Borchardt and Statzner, 1990), and morphological changes (Schueler, 1987). Changes in the sediment regime are particularly significant from the habitat point of view (Roesner et al., 2005). Contemporary stormwater management strives to mitigate these changes by preserving water balance and enhancing water quality.

6. Biotic Interactions

Biotic interactions include such processes as competition, predation, parasitism, feeding, reproduction and disease (Horner et al., 1994). These processes do affect biological integrity of surface waters, whenever their natural balance is disturbed. Anthropogenic impacts on biological interactions may include changes in primary and secondary production, disruption of life cycle, increased frequency of disease or parasitism, introduction of alien species, and changes in predator-prey and competitive interactions (Spence et al., 1996).

7. Conclusions

Urban drainage impacts on all major factors affecting the biological community performance, including food sources, water quality, habitat structure, flow regime, and biotic interactions. Some of these impacts are fairly acute and demonstrate themselves quickly (e.g., acute pollution), others, like habitat structure result from long-term interactions between the natural geomorphology, flow, erosion sediment transport, and riparian vegetation. Promising approaches to improving physical habitat in urbanization impacted streams include preservation of natural drainage features, sustainable development or redevelopment of urban areas, and balanced applications of stormwater management practices.

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URBAN RUNOFF – CONTAMINATION, PROBLEMS OF TREATMENT AND IMPACT ON RECEIVING WATER

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Abstract. In the paper the results of urban runoff chemical composition study in different seasonal periods and functional zones in Minsk are discussed. Increasing of contaminant concentrations in the receiving water downstream in urban area because of urban runoff impact are shown. The main pollutants (chlorides, natrium, suspended solids, heavy metals and oil products) of urban runoff are revealed. The problems of urban runoff treatment in Minsk are also under consideration.

Keywords: adverse impacts; pollutants; purification; receiving water; urban drainage system; urban runoff.

1. Introduction

Urban runoff is one of the important sources of receiving water contamination on urban area. Up to now in Belarus only 10 per cent of urban runoff are purified mainly from suspended solids and oil products. As a rule, urban runoff is transported via a separate drainage system to the receiving waters without purification, because the existent drainage system has been constructed without treatment plants for urban runoff. The control of contamination such type of water fluxes is also very difficult since the runoff outlets are often located below the water level. Besides one of the main problems of urban drainage is

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silting of canalisation because of sand application in winter period. In 2001 only in Minsk 2500 m^3 of sand was taken out of urban collectors.

Now there is a growing interest in the urban runoff in our country. Not purified urban runoff is the reason of numerous adverse impacts: transformation of receiving water chemical composition, increase of water temperature, toxic affect, etc.

An exploratory study of urban runoff contamination in different seasonal periods and functional zones, its impacts on receiving waters was undertaken in Minsk (the largest city of Belarus and its capital). Minsk is served by separate drainage system for runoff and sewage. The snowmelt water and rainfall runoff is transported via a stormwater sewer system to the Svisloch River. This system has some main collectors, which catch storm flow and carry it into the stormwater storage pond (Drazhnja) or small oil removers. There is also a system of small collectors, which has independent outflows into the Svisloch and its tributaries. Water from such collectors is not refined. It is considered that urban runoff contamination is not exceeded the standards for water which must be purified. A small part of urban runoff from the industrial zone is mechanically purified at local treatment plants. At the same time, our data indicate that urban runoff contains such pollutants as suspended solids, chlorides, natrium, nutrients, heavy metals and oil products (Khomich et al., 2003). Loads and concentrations of pollutants in urban runoff depend on rainfall characteristics, local atmospheric precipitation, drainage design, type of functional zone, traffic density, etc. (Barrett et al., 1998). At present time very limited data on this issue are available in Belarus.

2. Urban Runoff Contamination in Minsk

2.1. WINTER-SPRING PERIOD

In a winter-spring period snowmelt urban runoff is formed. The data on the chemical composition of snowmelt water from different functional zones in the Minsk area are summarized in Table 1.

The results of winter-spring survey show that in this period urban runoff strongly varies in contents of main ions for different functional zones. The highest solute content (more then 1000 mg/L) and value of pH is found in the urban runoff from residential and transport zones, as well as the maximum concentrations of suspended solids, chlorides, natrium and nitrites. The main source of such pollutants is an application of deicing agents in a winter period (mixture of salt and sand). As a whole the snowmelt fluxes from the urban area are characterized by higher concentrations of main ions as compared with runoff from a green zone.

TABLE 1 Maximum, minimum and mean concentrations of main ions in urban runoff in a snowmelt period, mg/L

Type of zone (samples quantity)	Concentrations	pH	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	NH_4^+	Na^+	K^+	Solute content	Suspended solids
					Urban runoff						
Green (4)	min	6.7	0.9	1.4	0.6	0.03	0.07	0.9	0.6	18.9	30.8
	max	7.8	21.3	2.7	2.3	0.09	0.23	7.8	7.3	88.5	78.7
	mean	7.5	11.2	1.9	1.5	0.05	0.17	4.8	2.9	54.7	59.9
Residential (14)	min	7.0	50.6	2.8	0.4	0.11	0.50	35.0	2.2	94.3	273.1
	max	10.6	2733.6	29.6	3.8	1.02	5.60	1750.0	30.0	4667.8	1412.0
	mean	7.9	594.2	15.0	1.7	0.49	1.67	385.2	11.4	1079.1	396.8
Transport (17)	min	7.4	805.1	7.4	0.4	0.24	0.16	610.0	7.8	1587.2	140.3
	max	8.6	14595.4	125.6	3.1	1.78	2.36	9600.0	187.5	24888.4	9699.0
	mean	8.1	3833.4	29.2	1.0	0.74	1.28	2309.7	47.4	6502.5	1770.5
					Atmospheric rainfalls						
Residential	mean	5.6	1.9	3.5	1.9	0.15	0.86	0.4	0.5	9.7	–

In water samples from different functional zones three forms of nitrogen were fixed. As known, nitrate form of nitrogen revealed in river waters testifies favorable conditions for oxidizing process (Barymova and Chernyschov, 1982). According our research, nitrate form dominates in runoff from a green zone. Snowmelt runoff from residential and transport zones primarily contains ammonium nitrogen indicating on weakly running processes of oxidizing. Receiving waters are enriched by mineral nitrogen found in runoff from zones above mentioned.

2.2. SUMMER-FALL PERIOD

In a summer-fall period rainfall runoff from urban area is forming when the depth of precipitation reaches more then 1 mm.

As a whole urban runoff from different zones has less concentration of main ion in a summer-fall period as compared to a winter-spring period (Table 2). As well as in a winter-spring period nitrate form of nitrogen dominates in runoff samples from a green zone. Stormwater runoff from residential and transport zones primarily contains ammonium nitrogen.

TABLE 2 Maximum, minimum and mean concentrations of main ions in urban runoff in a summer-fall period, mg/L

Type of zone (samples quantity)	Concentrations	pH	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	NH_4^+	Na^+	K^+	Solute content	Suspended solids
Urban runoff											
Green (4)	min	7.2	5.0	0.6	0.8	0.02	0.04	0.3	0.7	46.1	10.2
	max	7.6	10.4	4.0	3.5	0.07	0.08	4.3	1.3	73.4	30.0
	mean	7.3	7.5	1.9	1.7	0.05	0.06	2.3	1.0	56.9	22.1
Residential (8)	min	6.4	5.3	1.4	0.5	0.07	0.05	0.4	1.6	34.6	0.0
	max	8.7	21.7	19.3	4.0	1.07	3.70	11.0	13.0	203.4	578.5
	mean	7.5	9.4	7.3	1.7	0.46	1.46	4.9	6.0	105.1	159.1
Transport (5)	min	6.8	8.5	1.4	0.8	0.11	0.88	1.1	1.7	63.7	148.0
	max	7.7	17.7	9.3	2.8	0.91	3.84	12.2	9.1	140.1	395.5
	mean	7.3	11.6	5.4	1.8	0.32	2.19	5.4	4.2	97.1	261.5
Atmospheric rainfalls											
Residential	mean	6.6	0.1	1.7	2.1	2.57	1.08	0.3	1.1	22.3	–

The concentration of suspended solids in urban runoff from residential and transport zones is considerably diminished. The solute content decreases 50 times generally due to reduction of chlorides and natrium concentrations. At the end of a summer-fall period hydrocarbonates, calcium, and magnesium dominate in urban runoff from all functional zones. But increased concentrations of ammonium and nitrites are found out.

Thus, the results of surveys indicate that contamination of urban runoff primarily depends on a period of its formation and a type of drained functional zone. The runoff from a green zone is the cleanest. The storm flows from the streets and pavements are most of all contaminated.

2.3. CONTAMINATION OF WATER FROM URBAN DRAINAGE SYSTEM OUTLETS

In Minsk the stormwater sewer system has 1 collector (Drazhnja), that catches storm flow which spontaneously transports into a stormwater storage pond (Figure 1). In this pond the runoff is mechanically purified from suspended solids and oil products. Collectors Komarovka, Zapad, Tsentr and Aranskaja have only a small oil remover at the outlets. In spring the volume of runoff exceeds the capacity of the oil remover and contaminated water flows into receiving waters. There is also a system of small collectors, which have independent outflows into the Svisloch and its tributaries. The water from such collectors is not treated.

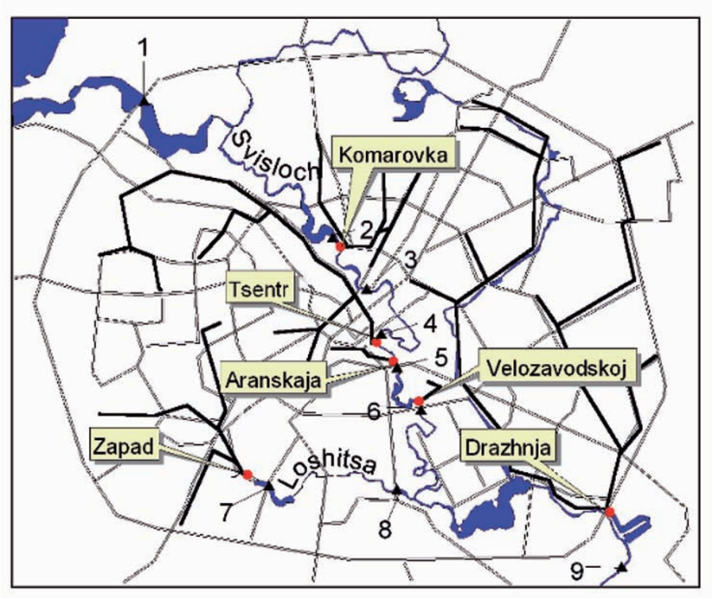

Figure 1 Scheme of urban drainage with main outlets in Minsk and monitoring places (1–9) on the Svisloch and Loshitsa Rivers

The chemical composition of water from stormwater sewer system outlets in 1999–2004 is summarised in Table 3. As evident from this table the mean concentrations of pollutants are not exceeded maximum permissible concentration (MPC) for urban runoff, with exception of suspended solids, BOD_5 and oil products. The highest mean concentration of oil products was marked in the outlets of collector Tsentr (1.6 mg/L). This collector drains a central part of Minsk – urban territory with high traffic density.

As known, the mean concentrations of contaminants can't reflect all extreme situations when MPC was exceeded. For example, maximum chloride concentration in the outlets of collector Tsentr was 7.6 times higher than mean concentration and exceeded MPC for urban runoff 2.5 times. The same situation was typical for collectors Aranskaja (5 MPC) and Velozavodskoj (7.3 MPC). The highest concentrations of chloride (885.0–2550.0 mg/L), solute content (1554.0–4586.0) and suspended solids (180.0–643.0 mg/L) were fixed in the snowmelting period, because of application of de-icing mixtures (about 15,000 tons of salt per year).

TABLE 3 Maximum, minimum and mean concentrations of main ions in water from urban drainage system outlets in 1999–2004, mg/L

Collector (samples quantity)	Concentrations	pH	Cl^-	NO_3^-	NO_2^-	NH_4^+	Solute content	Suspended solids	BOD_5	Oil products
Komarovka (24)	min	7.6	8.3	0.1	0	0.09	166.0	0	1.4	0
	max	8.6	221.9	5.2	0.16	4.88	576.0	56.0	28.5	1.67
	mean	8.1	40.9	1.04	0.04	0.79	298.9	14.8	5.96	0.31
Tsentr (24)	min	7.7	11.4	0	0.02	0.12	230.0	5.0	1.5	0.06
	max	8.5	885.0	5.2	0.21	2.5	1554.0	100.0	16.6	21.8
	mean	8.0	115.8	1.39	0.06	0.93	444.8	23.2	5.31	1.6
Aranskaja (24)	min	7.2	7.4	0.1	0.01	0.04	221.0	0	2.2	0.03
	max	8.5	1720.0	21.4	0.14	1.5	3510.0	643.0	25.8	5.45
	mean	8.2	163.0	1.7	0.03	0.45	550.9	61.0	7.0	0.77
Velozavodskoj (24)	min	7.8	8.8	0	0.01	0.03	228.0	0	1.2	0.05
	max	8.5	2550.0	5.5	22.3	1.86	4586.0	42.0	15.4	1.25
	mean	8.0	134.6	0.95	1.2	0.47	487.9	15.7	5.3	0.3
Drazhnja (24)	min	7.5	16.5	0	0.02	0.11	210.0	0	2.0	0.16
	max	8.2	208.3	36.5	0.31	2.98	1010.0	58.0	9.5	0.7
	mean	7.8	83.3	2.5	0.09	1.13	409.0	13.9	4.8	0.4
Zapad (24)	min	7.5	15.7	0	0.01	0.14	236.0	6.7	2.0	0.05
	max	8.7	91.4	3.0	0.71	7.2	578.0	180	25.4	1.4
	mean	8.0	47.3	0.73	0.09	1.63	340.8	34.4	6.5	0.3
MPC	–	–	350	10	1	2	1000	30	6	0.3

3. Urban Runoff Treatment in Minsk

The area of the stormwater storage pond (SSP) Drazhnja is 0.18 km^2. The pond is located on the outlets of collector Drazhnja that drains city territory of about 54.9 km^2 (25% of Minsk area). This pond was constructed in 1990. According to design, the accumulation of suspended solids amounts to 500 m^3 per year. Now conditions of the stormwater storage pond are satisfactory, the main part of the pond is silting.

In Belarus there are no guidelines for heavy metals concentration in sediment transported by urban runoff. Therefore, in this study for assessment of sediment contamination was used guidelines for the protection and management of aquatic sediment quality in Ontario (Marsalek et al., 1997). The concentration of heavy metals in the sediment from the storage pond is shown in Table 4 together with the Ministry of the Environment and Energy guidelines for the protection and management of aquatic sediment quality in Ontario.

Concentrations of such metals as zinc and copper are higher than the severe effect level (SEL) guidelines, indicating “gross pollution” of sediment that “will significantly affect” its use by benthic organisms (Marsalek et al., 1997). The maximum concentration of zinc exceeds SEL 1.4 times and copper – 6 times.

TABLE 4 Mean heavy metals concentrations in sediments transported by stormwater runoff ($\mu g \cdot g^{-1}$ dry weight)

Metal	Stormwater storage pond	Storm sewer outlets	MOEE guidelines severe effect level
Pb	107.9	36.7	250
Cd	0.9	1.2	–
Ni	46.4	60.7	75
Zn	691.2	995.4	820
Cu	318.7	511.5	110

The data on the chemical composition of water in the stormwater storage inlet and outlet are summarized in Table 5. The data of spring survey show that the main part of suspended solids settles in the storage pond. Their concentration in the pond outlet was decreased about 10 times compared with the inlet, but nevertheless 1.7 times exceeded MPC for suspended solids in the river water (30 mg/L).

TABLE 5 Chemical composition of water in the stormwater storage pond Drazhnja, mg/L (the spring survey)

Place of sampling	pH	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	NH_4^+	Na^+	K^+	Solute content	Suspended solids
SSP inlet	7.9	258	14.8	4.4	0.4	3.1	175	7.0	565.9	579.6
SSP outlet	7.6	485	26.4	4.4	0.5	3.5	320	10.6	1137.5	50.8

4. Impact on Receiving Water (the Svisloch River)

Two aspects of urban runoff impact on the Svisloch were examined: temperature impact and transformation of water chemical composition downstream rivers.

4.1. TEMPERATURE IMPACT

Temperature pollution due to urban runoff is one of impact types on receiving waters. Temperature rise of river water is a main reason of reduction of dissolved oxygen quantity. The water temperature in drainage outlets is usually higher than in the Svisloch (Figure 2). The largest differences in water temperature are typical for snowmelting period. For example, February 18, 2004 temperature in the Svisloch was only 0.5 ^{0}C, while temperature in the outlets reached 10 ^{0}C.

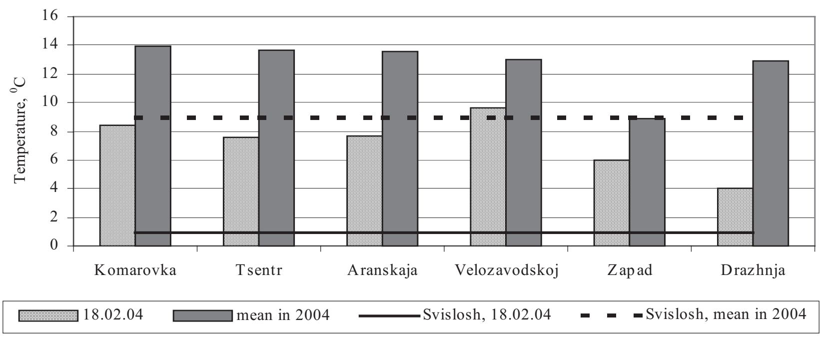

Figure 2 Water temperature in the urban drainage outlets and the Svisloch river February 18 2004 and mean temperature over a period of 2004

4.2. TRANSFORMATION OF WATER CHEMICAL COMPOSITION

The Svisloch is subjected to the anthropogenic load due to impact of urban runoff. Concentration of BOD_5, oil products, suspended solids, chlorides, and ammonium nitrogen gradually increases in water downstream of the Svisloch within the urban area (Figure 3).

Below the city (place 9) the mean concentrations of chlorides have increased 3.2 times, oil products – 3.0, ammonium nitrogen – 2.8, solute content – 1.7, BOD_5 and suspended solids – 1.4 times in receiving waters in comparison with place 1 (before city). Mean concentrations of the other ions have changed to a lesser degree.

The highest contamination of river water was typical for place 8 that describe water quality of the Loshitsa River. Mean concentration of chlorides has reached here 59.5 mg/L, solute content – 351.2, suspended solids – 31.5, ammonium nitrogen – 0.9, oil products – 0.2 mg/L and BOD_5 – 5,6 mgO_2/L.

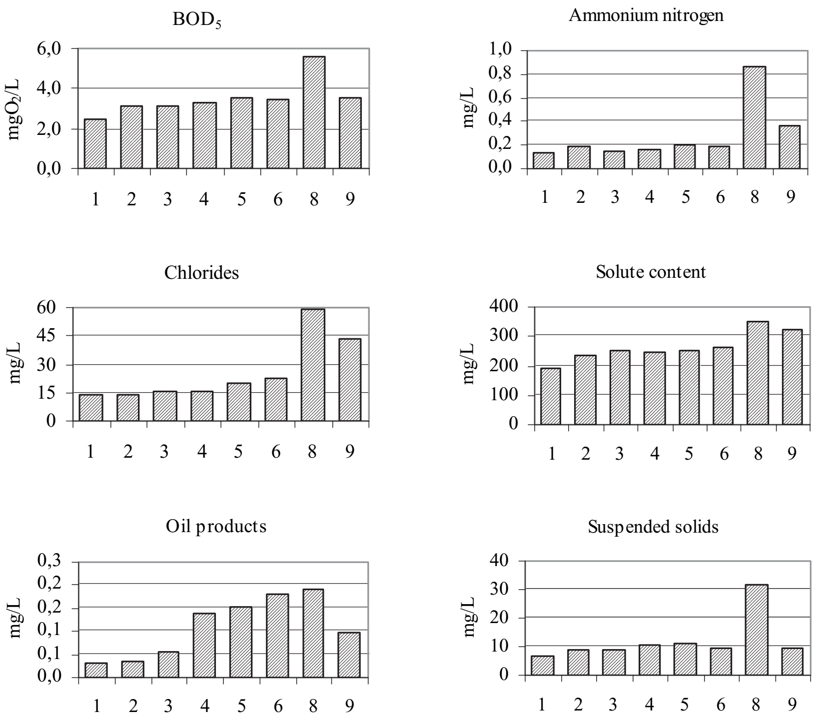

Figure 3 Contamination of water downstream of the Svisloch River in 2004 (1–9 monitoring places in the Figure 1)

The lower mean concentration of oil products in place 9 as compared with places 5, 6, 8 (central part of Minsk with high traffic density) depends on self-purification of Svisloch.

In the snowmelting period (February 18, 2004) the concentrations of oil products in water downstream (below Minsk) has increased 2.4 times, solute content – 1.9, chlorides – 6 times in comparison with the Svisloch water upstream (before Minsk).

5. Conclusion

Thus, the results of surveys show that urban runoff contamination primarily depends on a period of its formation and a type of functional zone. The urban areas with high traffic and pedestrian density produce severe contamination of urban runoff. Runoff from a transport zone contains maximum concentrations of oil products and heavy metals. Application of deicing agents in a winter period (mixture of salt and sand) is the main source of high concentrations of chlorides, natrium and suspended solids in water samples.

The process of purification of urban runoff in Belarus is not effective. In Minsk only a part of surface fluxes is purified from oil products and suspended solids in the stormwater storage pond. In snowmelting period such pond doesn't coup with a large volume of urban runoff and contaminated water fluxes runs into the receiving water (the Svisloch River). Additional purification from chlorides, natrium, and nitrogen are required.

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IMPACT OF ANTHROPOGENIC LOADS ON WATER QUALITY OF RIVERS OF THE UPPER AREAS OF OKA AND DESNA BASINS

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Abstract. The long-term integrated investigations of water quality of rivers at different streams with different anthropogenic loads of the upper areas of Oka and Desna basins on the territory of Kaluga Region testify that downstream from cities a 2-5–km zone with the increased values of determent indices is formed. The research of chemical composition of water and bottom sediments made for streams and water bodies within the cities and adjoining suburbs suggest the increased content of heavy metals resulted from man-made activity. Storm water runoff from the territory of the rivers catchments area is the main contributor to biogenic pollution. It has been determined that most polluted are small rivers running on the territory of large cities and receiving mainly municipal wastes and storm water runoff. Large anthropogenic load is typical for some small rivers with runoff forming on urbanized and economically developed territories.

Keywords: water quality; anthropogenic load; urbanized territory; pollution; heavy metals; biogenic elements.

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1. Introduction

The Kaluga region is 29.9 ths. km^2 and as shown by Semyonov and Semenova (2002) only 17% of it belongs to the basin of the Black Sea (the Dnepr River) while 83% is found in the basin of the Caspian Sea (the Volga River). The Volga basin covers the upper part of the *Oka* basin, the largest right-bank inflow of the Volga, and its inflows: the *Ugra*, the *Zhizdra* and the *Protva*. The Dnepr basin includes the left-bank inflows of the upper part of the *Desna* River: the *Bolva* and the Snopot rivers (see Fig.1).

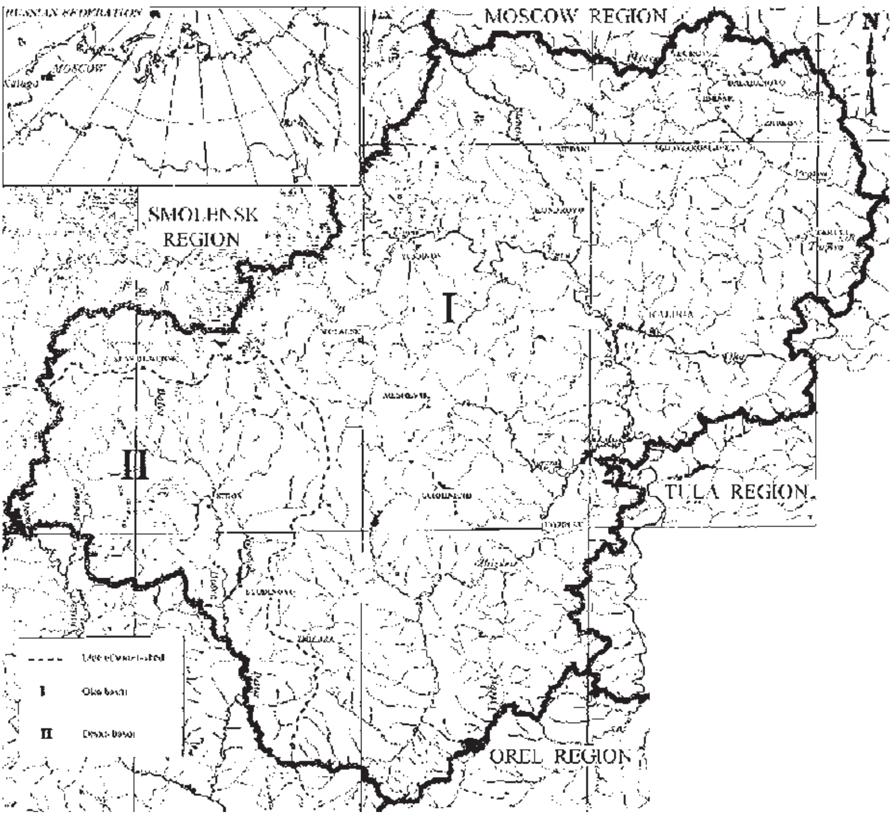

Figure 1 The map of surface waters of Kaluga region

The studies were performed on the rivers with different *residential*, *anthropogenic* and *man-caused loads*. The largest cities of the Kaluga region: Kaluga, Obninsk, Ludinovo, Maloyaroslavets and others are located in the basins of these rivers. Their *urbanized territories* influence the water bodies bringing about most strongly the changes in qualitative and quantitative features of water as compared to other anthropogenic factors.

2. Anthropogenic Load on River Basins

It has been found out that the total arrival of *pollutants* into *water bodies* depends on *residential load* and toxic substances coming from wastes discharges of industrial enterprise and storm waters from *urbanized territories* are accumulated in streams and water bodies in quantities which dangerous both for hydrobionts and for the health of the population.

Among anthropogenic factors responsible for water *pollution* and the change in hydrochemical regime of rivers the decisive role is played by waters returned from industrial, municipal and agricultural enterprises. The information (Semyonov and Semenova, 2002, Semyonov et al., 2004) about the water intake from the surface water bodies indicates that in recent years it has changed insignificantly and totaled 66.8 mln. m^3 per year, 66% of which being used for municipal needs. The largest amount of water discharge falls on the basins of the *Oka* and the *Protva*, where their share is 5-6% of the local runoff. Municipal wastes account for 80% of the total sewage requiring purification, industrial wastes account for 18% and agricultural wastes for 2%.

Table 1 gives estimates (in a point system) for the integral *anthropogenic load* on the river basins. Using this 100-point system, in addition to the area occupied with any of anthropogenic landscapes the degree of a landscape's impact on water runoff and quality was considered. Settlement and hard-surface roads got the maximum number of points, the minimum number was given to agricultural lands, orchards, vegetable gardens and rural roads. On the territory considered the largest load is observed in the basins of the *Protva* and *Bolva* rivers.

TABLE 1 Anthropogenic impact on small water body basins within the boundaries of medium river basins of the Kaluga Region

River basin	Basin area, km^2	Area, % of basin area, points								Point total
		Agricaltural lands		Settlements		Recreational territories		Hard-surface roads		
		%	points	%	points	%	points	km on 1 km^2	points	
Ugra	15300	38	4	4,3	43	7,8	8	0,15	15	70
Zhizdra	6940	50	5	3,8	38	6,0	6	0,14	14	63
Protva	3640	31	3	6,7	67	4,7	5	0,24	24	99
Bolva	3200	42	4	6,3	63	2,0	2	0,16	16	85

So, there is a definite relationship between population density, economic development of the territory and existence of settlement regions on the one hand and anthropogenic development of river basins on the other hand as well as between a share of urbanized (settlement) territories and pollution of surface water bodies (Semyonov et al., 2004). For the Kaluga Region these regularities appear in the following way: *anthropogenic load* and *pollution* of surface waters are decreasing from northeast to southwest, from the basins of *Nara* and *Protva* to the basins of *Ugra, Zhizdra* and *Desna*. At that most of the territory of the *Ugra, Zhizdra* and *Desna* basins is an agricultural geoecological region with insignificant industrial production and the territory of the *Protva, Nara* and *Tarusa* basins is an economically developed region with the highest population density.

The highest anthropogenic development - from 20 to 100% - is typical for small and very small rivers within the boundaries of industrial urban and suburban areas of Kaluga, Obninsk, and Maloyaroslavets

3. Water Quality Estimates of Large and Medium Rivers

The *water quality* changes of the upper *Oka* and *Desna* basins in the Kaluga Region were examined at different streams with different *anthropogenic loads*. The *Oka* appeared to be the only large river. Among medium-size rivers were the *Ugra*, the *Zhizdra*, the *Protva* and the *Bolva*.

A long-term series of observations for chemical composition of natural water carried out by the Roshydromet (1938-1999) allowed to study a hydrochemical regime of *major ions* and mineralization of the rivers of the upper *Oka* and *Desna* basins inflows in the territory of Kaluga region under natural and anthropogenic conditions using statistical methods as shown by Nikanorov and Tsirkunov (1991). Data given testified that practically all the rivers studied experience the *anthropogenic load* associated with the increase of concentration of the chloride and sulphate ion up to 200-300 % (Semyonov and Semenova, 2003). More significant seasonal variations in the *major ions* concentration were observed. The changes in natural hydrochemical regime can be thought to start at late 60s – early 70s.

The obtained results allowed to isolate three periods with different *anthropogenic load* (Semyonov and Semenova, 2003): 1) a period of *natural hydrochemical background* (1938-1959) with insignificant variations in the parameters studied; 2) a period of the so-called *initial anthropogenic load* (1960-1975) with violation of the natural hydrochemical regime of rivers that resulted in more or less quick increase concentrations of *major ions*; 3) a period of the *present-day anthropogenic influence* (from 1985 until now) which is characterised by continuous increase in the concentrations of ones *major ions* as well as some stabilisation of others.

The analysis of spatial distribution of *major ions* concentration (HCO_3^-, Ca^{2+}, SO_4^{2-} and Cl^-) and the total mineralization in the *Oka*, whose water is used for drinking, has shown that in the area examined no significant changes were noted (no more than 10-15%). The content of *biogenic elements* (mineral form of nitrogen and phosphorus: NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) in the summer low-water period did not exceed regulatory requirements, however as shown by Semyonov and Semenova (2002) downstream of large cities their concentration increased. Regulatory requirements are not met (increased concentrations) mainly during spring flood. Concentration of some *heavy metals* such as iron, copper, nickel and zinc also increased in this period. Downstream of the cities the value of biological oxygen demand (BOD_5) and the organic pollutants concentration (petrochemicals and surface active substances (SAS)) also increased.

The analysis of spatial distribution of *major ions* in the *Ugra* and the *Zhizdra* at different periods of hydrological regime was shown[1,5] that mineralization of water in the mid and lower *Ugra* did not change significantly, but concentration of chlorides and sulphates periodically increased (up to 50%) due to their arrival both with waters from more polluted lateral affluents and with organized discharges and storm water runoff.

The examination of *major ions*, *biogenic elements* and some pollutants (petrochemicals, SAS, *heavy metals*) in the *Protva* and the *Bolva* has shown that their concentration gradually increased from the head to the mouth (Semyonov and Semenova, 2002).

In general the studies results indicate that organized discharges and storm water runoff, especially sewage discharges of large settlements, and storm water runoff with increased concentrations of *biogenic elements* and pollutants influence the content of these components in the basins of the *Oka* and *Desna*.

4. Small Rivers on Urbanized and Economically Developed Territories

The large *anthropogenic load* is typical for some small rivers and water streams with the runoff forming on *urbanized* and economically developed territories. To assess the hydroecological state of small streams special studies were performed in the areas of Kaluga (see Fig.2), Maloyaroslavets, Obninsk and Lyudinovo. Samples of water and bottom sediments were analyzed using published methods (Manual on…, 1977).

The comparative analysis of water samples taken from the Yachenka (st.1-3), which is the northeastern marginal river of Kaluga, shows that in the suburban part of the basin up from the place, where the Yachenka meets the

Terepetz (st.4), water is close to natural as regards the content of *major ions* and total mineralization during all periods of hydrological regime.

Downstream of the Terepets confluence *water quality* in the Yachenka is deteriorated significantly. Essential changes are observed not only in the content of *biogenic elements* and dissolved organic matter (DOM) but also in that of such *major ions* as chlorides, sulphates and sodium, whose concentration increases 2-3 times. It is probably due to the fact that not adequately purified industrial wastes and polluted *storm water runoff* from the rural territory come to the river.

Figure 2 The scheme of water sampling in the area of Kaluga city

The Yachensk reservoir located in the mouth of the Yachenka serves as a natural collector of *pollutants* coming with the Yachenka runoff. Down from the reservoir water quality is better particularly in summer (Semenova et al., 2004, Strel'tsov et al., 2000). Therefore the processes of self-purification in the formation of the reservoir water should be taken into account. Among them are *sedimentation*, dilution and decomposition of compound organic substances.

Two small rivers, the Kaluzhka and Kievka, flow in the eastern suburban territory of Kaluga. In the Kaluzhka, which receives pollutants from orchards and vegetable gardens, only *biogenic elements* exceeded the norm in the summer low-water period. The Kievka almost along the whole length serves as a natural collector of industrial wastes and partly *storm water runoff* and municipal wastes. Already in the upper Kievka the total mineralization reached 855 mg/dm^3 by the end of the winter low-water period. In the middle part mineralization grew almost 3 times due to the significant increase in concentration of such *major ions* as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and chloride with the absence of changes in the content of *biogenic elements* and DOM (see Fig. 4). In the lower part mineralization decreases but concentration of biogenic elements increases (6-10 times). The increase of mineralization in the upper and middle Kievka and *biogenic elements* in the upper and lower Kievka is typical for other periods too. All these factors point to considerable *anthropogenic load* on the river. According to data (Semenova et al., 2004) the increase of *heavy metals* concentration is regularly observed in the water of the Kievka.

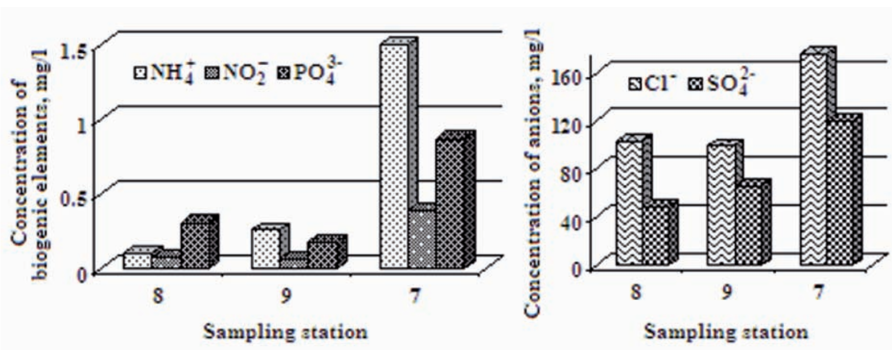

Figure 3 Change of concentration of the Cl^- and SO_4^{2-} and biogenic elements in the water of Kievka River

Studies performed in other settlements have shown that the most polluted are streams and small rivers of cities and large settlements receiving mainly municipal wastes, *storm water* and, sometimes, industrial runoff. *Biogenic elements*, ions of calcium, magnesium, sodium and sulphates and chlorides are observed there exceeding the norm. A number of metals, chemicals and SAS are found increasing in the streams receiving *storm water runoff* from city streets.

In the *Desna* river basin the studies were performed on the *Bolva* river and its inflow the Nepolod', in the month of which there is a large industrial city Lyudinovo and Lyudinovo reservoir used for complex purposes including household and drinking ones. Unlike the Yachenka whose water comes into Yachensk reservoir rather polluted the water of the Nepolod' does not undergo significant man-caused pollution. Yet observation of water-management bodies show that last 35 years the pollution of the Lyudinovo reservoir water has increased on such indices as colour and oxidity, ammonium and sulphate ions increased twice, iron content has become 9 times as large. At the same time the content of dissolved oxygen and fluorine has decreased.

5. Heavy Metals in Water and Bottom Sediments

To assess the impact of various anthropogenic and man-caused factors on the environment it is necessary to know the initial state of natural ecosystems, to forecast their changes with and without activity of industrial and agricultural organization. One of the approaches to reveal the negative ecological impact is to investigate the content of pollutant, in particular *heavy metals*, in the upper layers of bottom sediments of a water body, where natural and man-caused arrival of *heavy metals* is being fixed.

Water samples to analyze *heavy metals* were taken in the period of winter and summer low water of 2004 from the surface layers of the streams studied. The samples of upper layer of bottom sediments were taken during the summer low water period. The total concentrations of iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), nickel (Ni), cobalt (Co), chromium (Cr), lead (Pb) and cadmium (Cd) were determined in water and bottom sediments using atomic-absorption method (Manual on…, 1977).

The analysis of the total concentration of *heavy metals* in the water of the studied streams has shown the exceeded the norm of Cu and Mn almost in all rivers during all phases of water regime, of Fe in the Kievka river in the summer low water and in the small water flows in the Maloyaroslavets area during all phases water regime. It should be noted that Zn exceeds the norm in the winter period in the water flows which were subjected to heaviest man-caused load (the Terepets and Kievka rivers) as shown by Semyonov et al. (2004) and Strel'tsov et al. (2000). Overall, the concentration of most of *heavy metals* in water is higher in winter than in summer.

Bottom sediments of the most streams are sands, those of reservoirs are silted sands. Table 2 shows the data on *heavy metals* concentration in the upper layer of bottom sediments in the streams of Kaluga region.

Table 2 Heavy metals concentration in the bottom sediments of the Kaluga region streams, mg/kg of dry weight

Sampling station	Cd	Pb	Ni	Cu	Cr	Co	Zn	Fe	Mn
Kaluga area									
Yachenka river, st.1	0.09	15.8	6.84	8.76	26.9	3.49	38.3	19440	615
Yachenka river, st.3	0.05	3.72	2.04	2.04	12.2	0.68	9.92	1960	32.2
Yachensk reservoir, st.5	0.03	8.78	2.77	4.51	3.55	0.38	3.55	2830	103
Yachensk reservoir, st.6	0.03	4.77	1.60	0.91	5.36	0.22	5.36	1190	16.0
Terepets river, st.4	1.28	24.8	25.4	79.4	1.38	1.78	129	13300	274
Kievka river, st.7	0.07	7.23	4.69	16.3	5.79	0.92	5.79	3120	95.8
Maloyaroslavets area									
Karizha river	0.04	16.6	4.48	6.02	14.7	4.86	43.2	12150	568
Nechaika river	0.24	25.0	16.8	30.3	54.6	6.26	336	17030	762
Yaroslavka river	0.01	13.8	1.73	2.24	5.77	2.12	22.0	4880	208
Lyudinovo area									
Nepolod' river	0.01	0.86	0.78	0.75	1.35	-	4.25	1600	20.6
Lyudinovo reservoir, upper	0.19	10.4	7.11	4.98	9.00	-	31.8	10400	365
Lyudinovo reservoir, below	0.40	13.4	8.25	6.13	10.1	-	70.0	54000	860
Clarck (Perel'man,1979)	0.13	16.0	58.0	47.0	83.0	18.0	83.0	46500	1000

According to the results of the analysis the variation range of the total concentration of metals in the surface layer of bottom sediments is as follows: Mn -16-1120 mg/kg, Fe – 1190-54000 mg/kg, Zn – 3,55-336 mg/kg, Cu – 0,75-79,4 mg/kg, Cr – 1,35-138 mg/kg, Co – 0,22-6,26 mg/kg, Ni – 0,78-51,4 mg/kg, Pb – 0,86-88,9 mg/kg, Cd – 0,01-1,28 mg/kg.

Thus the diminishing series of concentration of *heavy metals* (*Fe>Mn>Zn>Cr>Pb>Cu>Ni>Co>Cd*) in bottom sediments of water bodies is almost analogous to that for the Earth's surface as shown by Perel'man (1979) (*Fe>Mn>Zn=Cr>Ni>Cu>Co>Pb>Cd*) and for the background values in the water of the world lakes as shown by Moore and Ramamurty (1978) (*Mn>Zn>Cu>Pb>Co>Cd*). The series differ only in Pb and Cu.

The analysis of absolute concentration values of *heavy metals* in bottom sediments indicates that of all streams in the Kaluga area the most polluted almost by all *heavy metals* the Terepets and Kievka. In Maloyaroslavets area the same is observed in Nechaika and Karizha. Concentration of some metals even exceeds Clark values in these rivers.

Data of *heavy metals* in water and bottom sediments in the Nepolod' and Lyudinovo reservoir show that in water of the reservoir the concentration of such *heavy metals* as Cd, Cu, Pb, Mn and Fe is three times higher than in the water of Nepolod’. The concentration of Cd, Cu, Cr, Mn, Ni, Pb, Zn and Fe in the bottom sediments of the reservoir rises 10-15 times.

Thus, the results obtained indicate that Lyudinovo reservoir bears heavy *anthropogenic load* which due to its specific character (low flowing ability, presence of stagnant zones), promotes accumulation of toxic pollutants can be the source of secondary *pollution* of the water body.

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BIOSORBENTS IN SURFACE WATERS IN SITU TREATMENT AGAINST RADIONUCLIDES

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Abstract. The method of water purification employing biosorbent of natural water reservoir, immobilized onto the fibrous carriers was suggested. The perifiton carriers were used for purification of natural water in Chernobyl zone canal falling into r. Dnieper. The developed onto carriers perifiton sorbs and holds radionuclides, their activity onto the biosorbent to be 3-4 order higher than that into the water. Both total and separate ^{137}Cs and ^{90}Sr β-activities, were determined to control radionuclide accumulation. At water/sorbent ratio of 1,2 m^3/kg water activity was found to be $0{,}42 \cdot 10^8$ and $3{,}92 \cdot 10^6$ Bk/m^3 for ^{137}Cs and ^{90}Sr respectivelly. In this case, the purification degree was 90,5 i 90,2%, respectively.The advantages of the method suggested are as follows: simple realization, environmental friendly, avoidance of the valuable expenditure and complex expensive equipment to produce the biosorbent, possibility of successfully purification of large volumes of the radioactive contaminated natural flowing water.

Keywords: biosorbent; fibrous carriers; hydrobiocenos; purification of natural water; radionuclides; ^{137}Cs; ^{90}Sr.

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1. Introduction

The technology of preliminary purification of natural waters using hydrobiocenoses immobilized on artificial (capron) fibrous carrier "VIYA" was developed in the Institute of Colloid and Water Chemistry (1). Since the problem of radioactive ^{90}Sr removal with surface runoff out of the Chernobyl Exclusion Zone still persists, we were set the task to determine effectiveness of given method for natural water deactivation.

The fact is that extraction from water of Chernobyl-derived ^{90}Sr, whose major part is dissolved in the free cation form (up to 91-97%), is very complicated process. Up to 6% of average ^{90}Sr concentration in surface waters falls at conditionally dissolved organic matters and up to 10-12% - at organogenic colloids and suspension. At present given radionuclide is carried over during destruction of fallouts fuel matrixes and is washed out from upper soil layer while infiltration of rainfalls and floodwater are present. Annual ^{90}Sr transport by Prypiat River to the Kyiv reservoir fully depends on the annual precipitation value (dryness of the year) and spring flood probability. Since 1995 the years with high spring flood (1999) and high summer flood (1998) were distinctly distinguished by annual ^{90}Sr transport equaled 10,2 TBq and 6,37 TBq, respectively at average annual value of 4,27 TBq.

Strontium passed into soluble or exchange form is not practically retained by mineral constituent of soil. The Chernobyl Exclusion Zone is located in the wooded zone (Polessie-Woodland) in the absence of effective natural barriers for ^{90}Sr, which is caused by low calcium and other cations content in the exchange soil complex, that essentially retards neutralization of humus acids. Weak-acid reaction of soil water solutions at high humidity facilitates migration of metals and their carry over into surface waters. Since solutions are characterized by high acidity and buffering as well as high content of organic matter, deactivation of natural waters reagent methods is ineffective and using mineral sorbents becomes rather complicated.

Thus, biosorption methods of water decontamination can be the most acceptable for given conditions. In given paper we consider the fibrous carrier of "VIYA"-type as a basis for biosorbent. Each "VIYA" bundle consists of 160-170 fibers with specific surface about 550cm^2/g. Just due to great specific surface the fibrous nozzle is capable to accumulate large amount of microscopic hydrobionts responsible for water purification.

The studies were divided into two stages – laboratory and field ones. The results of studies are presented in given paper.

Prior to laboratory tests the fibrous carrier was placed into natural watercourse for 12-40 days to achieve full immobilization of microorganisms.

In summer 2002 the *full-scale test* of technique for biological sorption on hydrobiocenoses fixed in "VIYA"-type carriers was performed at the watercourses within the Chernobyl Exclusion Zone.

Three rows of carriers were mounted at different distance from one another along the communicating channels, of which the last one drained into the Prypiat River. The first and second row were mounted in the channel section covered with concrete, the third row was mounted at 45m down of the second one in the uncoated channel with sandy-gravel bottom. Carriers with periphytonic hydrobiocenoses accumulated previously in the Nivka River (Kyiv City) were used at the 2^{nd} row.

2. Methods

Quantitative assessment of hydrobiocenoses immobilization was made through determination of protein content using Loury methods (in modification of N.S. Egorov) with preliminary hydrolysis of biofouling in the alkaline solution. Spectroscopic determination of protein in the hydrolysate showed presence of 622 mg of protein of microscopic organisms in 1g of biomass washed away from carrier.

Control over radionuclides accumulation on the hydrobiocenoses was realized by total β-activity and separately by ^{137}Cs and ^{90}Sr. The volumetric activity of ^{137}Cs and ^{90}Sr in the watercourse up and down of mounted "VIYA" rows was also determined. Discharge rate of channel directly before the second "VIYA" row was measured by hydrometric spinner while sampling of biosorbent and additionally 3-4 times a month – weekly.

During laboratory analyses of biosorption efficiency in *dynamic regime* model radioactive solutions in the column were run through biosorbent layer ($23 \cdot 10^{-2}$m) with velocity of $3{,}0.10^{-9}$m/s.

Total β-activity of samples was measured by β-radiometer KRK 1-01A. To determine volumetric and specific activities of ^{137}Cs in dried biosorbent sample (direct measuring) and water (after evaporating) γ-spectrometers of two types were used: γ-spectrometer based on the analyzer AI-1024-97 and γ-spectrometer SBS-55 with semiconductor detectors DGDK-80B3 and DGDK-80B. ^{90}Sr content in biosorbent samples was measured with the help of selective β-spectrometer RUB-91 produced by "Ardani". Within the range of measured activities (2-2000Bq/kg) inaccuracy of measurements didn't exceed 35%. For determination of ^{90}Sr volumetric activity in water samples and external verification of analyses results liquid-scintillation α-β-spectrometer "Quantulus-1220™" was used. Given device enables measuring of ^{90}Sr activity in the range of 10^{-2} -10^{6}Bq/kg (l). The basic measurement inaccuracy for analyzed solutions was 4-5%. For narrow tint range (from transparent to brown) of water samples the calibration procedure was performed, which enabled measurements to be made without exceeding of given inaccuracy.

3. Results

Laboratory experiment In the *dynamic regime* using the biocenoses accumulated on the "VIYA"carrier as a biosorbent led to essential decrease of ^{137}Cs and ^{90}Sr in artificial solution. Initial water activity was $4{,}4 \cdot 10^8$ Bq/m^3 for ^{137}Cs and $4 \cdot 10^7$ Bq/m^3 for ^{90}Sr. Activity of decontaminated water (at specific consumption of biosorbent = 1,2kg/ m^3 of water) equaled $4{,}2 \cdot 10^7$ Bq/m^3 - for ^{137}Cs and $3{,}92 \cdot 10^6$ Bq/m^3 – for ^{90}Sr, with decontamination degree 90,5% and 90,2%, respectively (Table 1). At that, specific activity of spent sorbent equaled $1 \cdot 10^7$Bq/kg and $9 \cdot 10^5$ Bq/kg for ^{137}Cs and ^{90}Sr, respectively.

TABLE 1 Volumetric activity of solution after decontamination (A_{fin}), specific activity of spent biosorbent (C_{sb}), degree of water decontamination (DD) from ^{137}Cs and ^{90}Sr, %, obtained in laboratory conditions

Biomass accumulated on the carrier, [g/kg]	Period of biomass accumulation, [days]	^{137}Cs			^{90}Sr		
		A_{fin} [Bq/m^3]	C_{bs} [Bq/kg]	DD [%]	A_{fin} [Bq/m^3]	C_{bs} [Bq/kg]	DD [%]
10	12	$0{,}84.10^8$	$0{,}9.10^7$	81,0	$0{,}84.10^7$	$7{,}8.10^5$	78,8
15	36	$0{,}42.10^8$	$1{,}0.10^7$	90,5	$0{,}39.10^7$	$9{,}0.10^5$	90,2
20	40	$0{,}21.10^8$	$1{,}05.10^7$	95,2	$0{,}30.10^7$	$9{,}2.10^5$	92,4

Carrying out of experiment in *circulation regime* resulted in higher degree of deactivation. Thus, at ^{137}Cs activity of 80 Bq/dm^3 in initial water, the subsequent decrease in activity was observed down to 2 Bq/dm^3 and less.

In the channels within the Chernobyl Exclusion Zone sampling of "VIYA" fibers were made in fixed time intervals: at first – in five days, further - in a week, in two weeks, in three weeks and once a month. At the same time the water and air temperature as well as discharge rate of the channel were measured, which allowed comparing the dynamics of radionuclides sorption by biomass with environmental conditions of hydrobiocenoses vital activity (Fig.1).

Total β-activity of water sampled from the channel K-90A while mounting of "VIYA" carriers (end of July) was about 36Bq/l (19,77 Bq/l – in solution + 17,24 Bq/l – in suspension). At that time ^{90}Sr and ^{37}Cs activities in solutions accounted to 15Bq/l and 5,4 Bq/l, respectively. Water in the channels has hydrocarbonate-calcium chemical composition. The value of permanganate oxidation varried from 30 to 18 mg O/l (maximal allowable concentration is 4-5 mg O/l, according to Standards of Ukraine and EC-98) over the period of July-September.

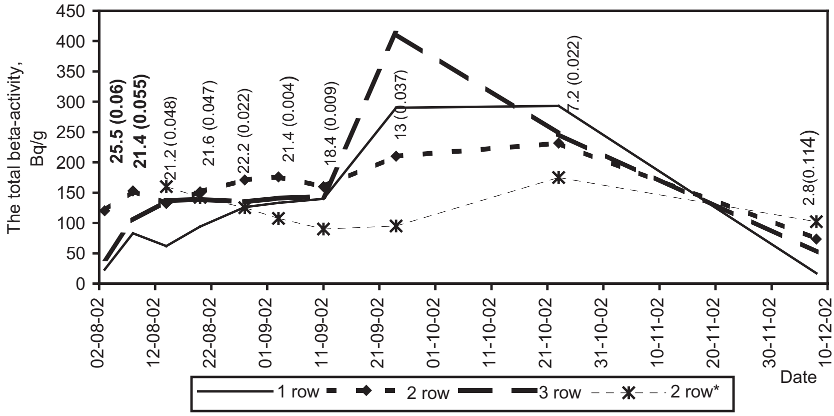

Figure 1 Changes of total β-activity of biosorbent in the course of full-scale test, 2002. Values above sampled points indicate: water temperature, °C (discharge rate of the channel, m3/s); * - "VIYA" with previous biofouling.

At completion of testing (8.12.2002) maximal specific activity of ^{90}Sr and ^{137}Cs in autochtonous biofoulings was fixe at 580Bq/g and 700 Bq/g, respectively (2nd row). As compared to initial stage of test (August 3 and 8), by December ^{90}Sr and ^{137}Cs specific activity in biomass increased, namely: at the 1st row – by 5 and 7 times, at the 2nd row – by 3 and 2 times, respectively. At the 3rd row ^{90}Sr and ^{137}Cs specific activity remained practically unchanged over given period.

Down of the 3rd row decrease of ^{90}Sr volumetric activity in water was fixed, as compared to that sampled before the 1st and 2nd rows. Maximal degree of decontamination from ^{90}Sr was achieved at the flow rates of 10-20 l/s and equaled 50-54%.

Maximal accumulation of ^{90}Sr by biocenoses occurred over the first 2-2,5 months when water temperature was no less than 13°C.

It has been estimated the accumulation kinetics of the radioactive elements on a carrier with the hydrobiocenosis fixed. The results of these studies are shown in Table 2.

TABLE 2 The accumulation kinetics of the beta-activity from waters of the hernobyl zone canal on the biosorbent

Biosorbent	Total β-activity, [Bk/g]		
	20.07	14.08	8.12
The fibrous carrier which is placed in the upper layers of flowing water	0	110±10 (^{137}Cs) 16±2 (^{90}Sr)	176±16 (^{137}Cs) 66±4 (^{90}Sr)
The fibrous carrier which is placed near the sludgy bottom	0	346±35 (^{137}Cs) 198±5 (^{90}Sr)	685±66 (^{137}Cs) 576±12 (^{90}Sr)

4. Discussion

Probably, since fibrous carrier has certain limit of biomass accumulation, after a time activity of "VIYA" samples with previously fixed relatively "pure" hydrobiocenoses in the Nivka River does not increase significantly (Fig.1). "VIYA" samples without previous biofouling accumulate autochtonous biocenoses having been already contaminated. At that, specific activity of biomass increases more intensively.

Although the absolute value of ^{137}Cs sorption on the carrier and in hydrobiocenoses is greater than that of ^{90}Sr, intensity of ^{90}Sr accumulation over the period of August-December was higher. Concentration of ^{90}Sr in water is higher than that of ^{137}Cs. Perhaps, this fact determines greater accumulation of ^{90}Sr in chitin of hydrobionts (also taking into account its bone-seeking features). So, accumulation of ^{90}Sr on the carrier increases as biomass grows and evolves. At the same time ^{137}Cs sorbed by suspended particles (suspension radioactivity is associated mainly with ^{137}Cs) is retained on "VIYA" fringe immediately after its dipping into the watercourse. However, retention of such particles by carrier is of short duration, because it depends more strongly on hydrodynamic conditions than ^{90}Sr sorption from solution by biomass.

Decrease or slowing down of ^{90}Sr and ^{137}Cs accumulation on the carriers at the 3rd row coincides with low intensity of biofouling. This can be explained, on the one hand- by interception of involved hydrobionts by adjacent 2nd row, on the other hand – by unfavorable conditions due to absence of channel coating, which results in increase of mineral suspension in water flow.

Total specific β-activity of biosorbent mainly associated with ^{90}Sr, practically does not depend on changes of water temperature in the range of 13-28^{o}C. However, with coming of autumn cold weather and dropping of temperature below 10^{o}C, significant decrease of biosorption intensity (in the 1st and 2nd row) and even decrease of total β-activity (in the 3rd row) is observed (Fig.1). Change of water discharge rate also doesn't exert any significant effect on the accumulation process. Explained negative correlation coefficients between accumulation and discharge rate (from –0,22 in the 3rd row to –0,52 – in the 2nd row) are somewhat understated because of prevailing tendency of biomass increase without regard to natural factors change.

Probably, maximal intensity of biofouling and radionuclides biosorption is possible at flow rate less than 30 l/s that imposes certain limits on application of given method of deactivation or requires conditions for separation and deceleration of flow. More actual and economically expedient is application of a large amount of “VIYA” carrier rows (up to 20-30) without changing the channel configuration.

For certain flow rates and radionuclides concentrations the necessary number of “VIYA” rows was calculated. For example, to achieve 85-90% deactivation degree of water in the watercourse with discharge rate of 0.06 – 0.12 m^3/s and volumetric activity of 9-15 Bq/dm^3, 20 “VIYA” rows are necessary.

As might be seen of Table 2, ^{90}Sr is accumulated to a lower extent than ^{137}Cs. This is especially discerned in the cases where a carrier with the biocenosis was immediately allocated near the sludgy bottom. This is confirmed by the fact that apart from the biosorbent cesium is also absorbed by the clayey particles that were placed on the fibrous carrier lain down immediately to the sludgy bottom. This is in a close agreement with the data we established in the past that cesium is better absorbed by the natural minerals as compared with strontium, and this is due to the structure of these minerals.

Thus, the biosorbent (that is, the hydrobiocenosis fixed on the fibrous carrier) as well as the natural clayey minerals which are retained on the carriers at purification of waters under the natural conditions remove effectively ^{137}Cs and ^{90}Sr from the radioactively contaminated waters. The biosorbent is simple in its technological implementation and provides a simple removal of the carrier with the radionuclides accumulated onto it giving so a way to make next them harmless. Cost associated with obtaining of the biological sorbent is low enough. It should also be stressed a likelihood in application of this method to purify the flowing radioactively contaminated waters under the natural conditions.

The principle disadvantages of “VIYA” carriers as well as of the most biofilters are their certain dependence on water temperature and deactivation degree as well as concentration of carrier elements in decontaminating waters.

The advantages of described above method of radioactive water decontamination are as follows:

- given method provides rather high degree of water deactivation from ^{137}Cs and ^{90}Sr (up to 90%) due to high density of biofouling by local hydrobionts and high contact with water;

- given method is technologically easy to operate both in sorbent preparation and its further use in the course of water decontamination; moreover it provides for easy extraction of spent biosorbent from water and reuse of carrier after its regeneration if necessary;
- costs of biological sorbent production are rather small.

The above advantages ensure the possibility of effective application of described method for decontamination of radiocontaminated natural watercourses.

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WASTEWATER TREATMENT AND SECURITY

ECONOMIC AND TECHNICAL EFFICIENCY OF WASTEWATER PLANTS: A BASIC REQUISITE TO THE FEASIBILITY OF WATER REUSE PROJECTS

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Abstract. The water reuse could be considered essential both from a social and also an environmental and health point of view. In light of the growing importance of water reuse as an alternative source of water resources in many regional areas, the objective of this paper is to analyse the efficiency of wastewater treatment plants. Efficient performance, both in technical and economic terms favours reuse possibilities and, therefore, increases the water supply. An analytical benchmarking methodology based on non-radial measures gives us an efficiency indicator for each input considered in the wastewater treatment process. These indicators, obtained by means of mathematical programming techniques, are used to rank plants' activity through a Variance Analysis.

Keywords: benchmarking methodology; efficiency indicator by input; mathematical programming techniques; non radial measures; technical efficiency; wastewater treatment plants; water reuse.

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1. Introduction

Water reuse could be considered indispensable, both from a social and also an environmental and health point of view. The series of benefits or externalities that stem from the use of treated water in many cases support its use. Some of these benefits are derived from the reuse of pollutants (nitrogen and phosphorous can be reused in agriculture, mud in agriculture and gardening and thermal energy can be reused), the use of the resource (the amount of water available is increased, supply is guaranteed in times of shortages and water quality can be adapted to different uses), environment (the water level of rivers is increased, contamination of masses of water is avoided and wetlands and rivers can be recovered), or social (contributes to social awareness of a new water culture).

In spite of water reuse is a very good practice because it allows the recovery of water resources and also because it reduces environmental impacts, it is no less true that economic variables, such as cost and price, mainly influence the use of treated water in relation to other available resources.

In this sense, a classification of the use of these non-conventional resources with their respective quality parameters enables the most suitable water treatment technology for each case to be determined. Furthermore, an efficiency analysis of the wastewater treatment process is required in order to achieve the feasibility of water reuse projects.

Efficient performance, both in technical and cost terms favours reuse possibilities and, therefore, increases the supply of the so-called non-conventional resources. Recently, Hernandez and Sala (2005) carried out an efficiency analysis using DEA Models for a sample of wastewater plants located in Spain (the Valencia Region). The present work intends to advance in the same line but applying a methodology based on the non-radial measures of technical efficiency with the aim of calculating an efficiency indicator for each input used in the wastewater treatment process.

2. Methodology

The efficiency concept is used to describe the optimal use of all the production factors in a production process, in accordance with the existing technology. Farrell (1957) becomes the pioneer in the research of frontier functions used as references to obtain efficiency measurements for each productive unit. When a plant obtains maximum output given a certain input vector, or uses minimum inputs to produce a certain output, it will be on the so-called production frontier. In this last case, the technical efficiency of a plant can be measured by calculating the maximum possible proportional reduction in the use of factors that are compatible with its output level.

Despite the widespread presence in the literature of empirical research based on efficiency analysis, contributions in the field of the environment and more specifically in the area of wastewater management remain scarce. Practically all existing papers have concentrated on either analysing changes in the productivity of a series of plants related to water in the urban environment (Marques and Monteiro, 2003, 2005), or covering the impact of privatisation and regulation processes on the water industry in terms of efficiency (Saal and Parker, 2000, 2001; Parker, Saal and Weyman-Jones, 2002) and above all else, on the efficiency of water price fixing (Garcia and Reynaud, 2004).

Following Hernández and Sala (2005), the present paper sets out to measure the efficiency of wastewater treatment processes with the aim of obtaining efficiency indicators for each input used in the process. This information is essential for valuing the potentiality of water reuse in an area, particularly in terms of costs. In order to achieve this, we assume a production process in which from a vector of inputs $x \in \Re_{+}^{N}$ a vector of outputs $y \in \Re_{+}^{M}$ is obtained by using technology T, in such a way that,

$$T = \{(x, y); x \; can \; produce \; y\} \tag{1}$$

This technology T can also be expressed in an equivalent way from the inputs point of view, which is,

$$(x, y) \in T \Leftrightarrow x \in L(y) \tag{2}$$

Where $L(y)$ represents the set of inputs vectors *x* that allow them to reach at least one vector of outputs *y*.

Under the assumption of constant returns to scale and strong disposability in inputs[1], Färe and Lovell (1978) design the *non-radial* measures or Russell's measures with the aim of satisfying a set of axioms that should be meet by any measure of efficiency, $E(y, x)$. These measures are obtained by minimising the arithmetical mean of the efficiency indices in input per plant and is,

$$MR(y, x) = min\left\{\sum_{n=1}^{N} \lambda_n / N : (\lambda_1 x_1, \lambda_2 x_2, ..., \lambda_N x_N) \in L(y), 0 \le \lambda_n \le 1\right\} \tag{3}$$

In this case the different inputs are minimised in different proportion, in contrast with the radial measure in which all inputs are reduced by the same

[1] In inputs, strong disposability is when an input may be increased without any cost in terms of increases in the rest of inputs, to maintain the level of output constant.

proportion. This degree of flexibility ensures Russell's measure always uses the subset of efficient points as a reference.

Given $K = 1,2,...,k,...,K$ plants each one of which uses a vector $x^k = (x_1^k, x_2^k, ..., x_N^k)_{(Nx1)}$ of inputs to carry out the production of a vector of outputs $y^k = (y_1^k, y_2^k, ..., y_M^k)_{(Mx1)}$, z being an intensity vector of variables (Kx1). For each plant k we can obtain the values of Russell's measures by solving the following optimisation problem using linear programming[2]:

$$
\begin{aligned}
& MR(y^{k'}, x^{k'}) = 1/N \min \sum_{n=1}^{N} \lambda_n \\
& s.t. \\
& \sum_{k=1}^{K} z_k y_{km} \geq y_{k'm} \; m = 1,...,M \\
& \sum_{k=1}^{K} z_k x_{kn} \leq \lambda_n x_{k'n} \; n = 1,...,N \\
& z_k \geq 0, \; k = 1,...,K \\
& 0 \leq \lambda_n \leq 1, \; n = 1,...,N
\end{aligned}
\tag{4}
$$

where *MR* corresponds to Russell's measures while each λ_n obtained gives us an efficiency indicator for each input considered. Efficiency would mean that reducing the quantity of this input is impossible, while inefficiency would imply more possibilities of minimizing it.

We will now proceed to the empirical application based on the use of this methodology on a sample of wastewater plants whose description is showed below.

3. Sample and Variables

The sample in this paper consists of 202 plants located in Spain (the Valencia Region). Each plant carries out a process that is characterized by the presence of an *output, waste obtained from wastewater* (y_1) and five *inputs*: *energy cost* (x_1), *labour cost* (x_2), *maintenance cost* (x_3), *waste management cost* (x_4) *and other costs* (x_5). These variables are described in *Table 1.*

[2] See Färe, Grosskopf and Lovell (1994)

TABLE 1 Sample Description (202 Plants)

Variable	Description	Units	Mean
y_1	Waste obtained from wastewater	Kilograms	90,176.24
x_1	Energy Cost	Euros	13,389.18
x_2	Labour Cost	Euros	28,275.99
x_3	Maintenance Cost	Euros	5,557.58
x_4	Waste Management Cost	Euros	5,084.18
x_5	Other Costs	Euros	23,220.31

4. Results

This involves resolving the exercise of mathematical programming (4) where $K = 1,2,...,k,...,202$ plants that each use a vector $x^k = (x_1^k, x_2^k, x_3^k, x_4^k, x_5^k)_{(5x1)}$ of inputs to obtain a vector of *outputs* $y^k = (y_1^k)_{(1x1)}$, z being a vector of dimension (202x1). The results obtained from the 202 optimisation programmes (one per productive unit) give a mean value of 0.4423 for Russell's measures (*Table 2*). This means that the set of analysed plants could obtain the same output saving themselves 56 percent of the inputs in total. The indicators associated with each of the inputs are fairly divergent among themselves corresponding the lower values to *waste management cost* (0,3354) and *maintenance costs* (0,3384), which represent a reduced efficiency level in the management of these inputs for the total number of plants from the sample.

Once these indexes have been obtained, we aim to assess the possible relationships between these efficiency indicators in inputs and the size of the plant, expressed in terms of the volume of wastewater treated. In order to achieve this, a *second stage* analysis is undertaken. From among the few options the literature provides, we chose to carry out a *Variance Analysis*, as it was the most suited to our objective. This entails ascertaining whether or not there are significant differences in the mean values obtained in the efficiency indicators, between the various groups in which the sample plants have been divided, in terms of their size.

With this in mind, the variance analysis was carried out and the F statistic led us to reject, with five per cent significance, the hypothesis of equality of means for all the indicators of input efficiency (except *other cost index*) across the five different plant sizes specified. When observing the mean values for each group in terms of Russell measure, smaller plants are seen to be more inefficient (0.4021) compared to larger plants (0.6294). In the first case, the plants under consideration could reduce their input costs by approximately 60%, compared to a possible reduction of 37% in the second case, while

TABLE 2 Results for Russell's measures

Plant	Russell Measure	Energy Cost Index	Labour Cost Index	Maintenance Cost Index	Waste Management Cost Index	Other Cost Index
1	0,2683	0,1117	0,2146	0,2198	0,4128	0,3828
2	0,6414	0,8904	0,3942	0,3517	0,8603	0,7103
3	0,2250	0,1795	0,3669	0,0575	0,0556	0,4653
4	0,2347	0,0432	0,6049	0,1268	0,0089	0,3897
5	0,2884	0,1546	0,5933	0,1239	0,0303	0,5399
6	0,2720	0,1455	0,5829	0,1240	0,0084	0,4992
7	0,7551	0,4735	0,8922	0,5954	0,8726	0,9416
8	0,4851	0,5884	0,5975	0,6532	0,0950	0,4915
9	0,5531	0,2188	0,6505	0,4920	0,6012	0,8032
10	0,2612	0,2606	0,4078	0,0585	0,0959	0,4834
11	0,2005	0,1620	0,2483	0,1462	0,0531	0,3931
12	0,3847	0,6961	0,2617	0,2626	0,3046	0,3985
13	0,5234	0,4496	0,4845	0,5550	0,4259	0,7022
14	0,2903	0,2559	0,2634	0,2499	0,1932	0,4893
15	0,2756	0,1909	0,4899	0,1074	0,0475	0,5425
16	0,1898	0,1474	0,3296	0,0612	0,0195	0,3911
17	0,2588	0,2364	0,4076	0,0662	0,0987	0,4849
18	0,3307	0,3677	0,4202	0,1263	0,2463	0,4932
19	0,7107	0,6815	0,9733	0,5756	0,3292	0,9941
20	0,5046	0,7312	0,4478	0,4518	0,1606	0,7317
21	0,6202	0,6890	0,4575	0,7768	0,4473	0,7305
22	0,3496	0,2429	0,4834	0,1549	0,1827	0,6842
23	0,1191	0,1034	0,1887	0,0480	0,0471	0,2082
24	0,7224	0,4590	0,8837	0,5160	0,8205	0,9329
25	0,7155	0,3535	0,8785	0,5329	0,9064	0,9061
26	0,7596	0,4743	0,9709	0,5741	0,8104	0,9683
27	0,8507	0,5751	1,0000	0,9962	0,7078	0,9744
28	0,2536	0,2841	0,2686	0,1661	0,1777	0,3713
29	0,2538	0,2135	0,3573	0,1268	0,1169	0,4546
30	0,2676	0,2316	0,4775	0,0888	0,0947	0,4452
31	0,2403	0,3786	0,2244	0,2025	0,0828	0,3133
32	0,2262	0,1431	0,3919	0,0597	0,1194	0,4169
33	0,2824	0,2334	0,3243	0,1887	0,2511	0,4145
34	0,2652	0,2409	0,6030	0,0638	0,0420	0,3764
35	0,6088	0,3188	0,8991	0,4521	0,4830	0,8912
36	0,4032	0,5860	0,4466	0,1855	0,2412	0,5569
37	0,3765	0,6156	0,3731	0,2912	0,1263	0,4763
38	0,2744	0,2465	0,4604	0,0858	0,0991	0,4801
39	0,3976	0,4002	0,4685	0,2742	0,3363	0,5086
40	0,4623	0,5036	0,6127	0,1737	0,1990	0,8226
41	0,3543	0,2770	0,4408	0,2733	0,3020	0,4784
42	0,2509	0,1422	0,3451	0,2439	0,0479	0,4753
43	0,5119	0,3569	0,5649	0,5214	0,6378	0,4783
44	0,6880	0,6202	0,6311	0,8370	0,5511	0,8008

Plant	Russell Measure	Energy Cost Index	Labour Cost Index	Maintenance Cost Index	Waste Management Cost Index	Other Cost Index
45	0,4521	0,2937	0,6365	0,3954	0,3532	0,5818
46	0,2920	0,2772	0,4686	0,0965	0,1383	0,4794
47	0,4916	0,2372	0,6444	0,4341	0,3731	0,7690
48	0,6772	0,2809	0,9749	0,6491	0,6198	0,8615
49	0,1763	0,1071	0,2922	0,0683	0,0885	0,3255
50	0,3134	0,3000	0,3902	0,2471	0,1194	0,5104
51	0,3845	0,3159	0,4441	0,5570	0,1455	0,4599
52	0,2153	0,2181	0,2999	0,0760	0,0980	0,3845
53	0,3883	0,3328	0,6371	0,1821	0,0642	0,7255
54	0,2919	0,2155	0,4565	0,1292	0,0444	0,6139
55	0,5368	0,6494	0,8032	0,2479	0,1157	0,8679
56	0,2896	0,2911	0,3866	0,1074	0,2119	0,4512
57	0,6210	0,7056	0,4145	0,9014	0,5365	0,5470
58	0,3004	0,2992	0,3666	0,2332	0,1184	0,4844
59	0,3711	0,4796	0,4204	0,2480	0,2289	0,4786
60	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
61	0,4617	0,4944	0,6855	0,6245	0,0265	0,4775
62	0,3460	0,4079	0,4227	0,2041	0,2169	0,4782
63	0,2867	0,2511	0,4540	0,1022	0,1406	0,4858
64	0,2989	0,3584	0,4838	0,1822	0,0679	0,4024
65	0,3417	0,3023	0,5088	0,1353	0,2433	0,5190
66	0,4936	0,6176	0,3104	0,1982	0,7589	0,5828
67	0,2948	0,2745	0,2186	0,1076	0,3904	0,4830
68	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
69	0,6469	0,6819	0,9852	0,2300	0,4319	0,9056
70	0,2550	0,2544	0,3664	0,0922	0,1747	0,3873
71	0,4518	0,4883	0,5480	0,3591	0,3013	0,5625
72	0,2692	0,2549	0,4105	0,1385	0,0940	0,4480
73	0,2771	0,2466	0,3792	0,1310	0,1690	0,4595
74	0,3435	0,4375	0,4271	0,2209	0,1617	0,4701
75	0,2145	0,2760	0,1936	0,1547	0,0130	0,4350
76	0,3533	0,4462	0,3357	0,1871	0,2065	0,5908
77	0,5094	0,6244	0,5451	0,2745	0,4185	0,6843
78	0,3488	0,4147	0,3516	0,2859	0,1151	0,5767
79	0,4535	0,3730	0,5148	0,3441	0,5163	0,5193
80	0,3267	0,3020	0,4566	0,1680	0,1690	0,5378
81	0,5137	0,5746	0,5926	0,4815	0,3615	0,5581
82	0,3422	0,3536	0,5061	0,1892	0,1415	0,5208
83	0,4742	0,4556	0,4464	0,6420	0,1555	0,6714
84	0,3369	0,3280	0,7261	0,1030	0,0961	0,4314
85	0,3352	0,3015	0,4241	0,2584	0,1482	0,5439
86	0,2204	0,2461	0,2642	0,0915	0,1377	0,3625
87	0,2844	0,1778	0,5012	0,1428	0,1632	0,4372
88	0,3152	0,2758	0,5120	0,1251	0,1720	0,4909
89	0,3408	0,2887	0,4107	0,1253	0,4297	0,4497
90	0,6179	0,7641	0,9220	0,2443	0,3305	0,8286

Plant	Russell Measure	Energy Cost Index	Labour Cost Index	Maintenance Cost Index	Waste Management Cost Index	Other Cost Index
91	0,2486	0,2229	0,4147	0,1308	0,1015	0,3730
92	0,5321	0,5582	0,6369	0,2635	0,4467	0,7553
93	0,1883	0,1834	0,3268	0,0902	0,0997	0,2412
94	0,5057	0,5608	0,3359	0,8336	0,2440	0,5544
95	0,5793	0,5684	0,9735	0,2748	0,1050	0,9746
96	0,4797	0,6340	0,6042	0,1896	0,2889	0,6817
97	0,2379	0,1758	0,3427	0,1401	0,1834	0,3477
98	0,4617	0,5478	0,5351	0,3323	0,2596	0,6339
99	0,3608	0,3360	0,5492	0,1914	0,1566	0,5710
100	0,2924	0,2945	0,4368	0,0969	0,1472	0,4867
101	0,4214	0,4150	0,4942	0,2458	0,4144	0,5374
102	0,2795	0,1925	0,5411	0,2810	0,1354	0,2477
103	0,3934	0,4867	0,4821	0,2298	0,2403	0,5281
104	0,4038	0,3947	0,4871	0,2525	0,2175	0,6670
105	0,2043	0,1753	0,2975	0,1010	0,0784	0,3695
106	0,2491	0,1666	0,3713	0,1152	0,1690	0,4236
107	0,6279	0,9487	0,5977	0,4485	0,4843	0,6603
108	0,4410	0,4498	0,2835	0,5387	0,4049	0,5281
109	0,3292	0,2577	0,5235	0,1758	0,2338	0,4550
110	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
111	0,1600	0,1253	0,2591	0,0884	0,0687	0,2585
112	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
113	0,3431	0,3014	0,4684	0,1434	0,2560	0,5461
114	0,2496	0,2654	0,2972	0,1353	0,1644	0,3859
115	0,6036	0,4884	0,7736	0,9109	0,1501	0,6951
116	0,6572	0,6919	0,8328	0,6769	0,0844	1,0000
117	0,4383	0,4442	0,5713	0,2952	0,3809	0,5001
118	0,6119	0,5566	0,7291	0,5186	0,4647	0,7907
119	0,3390	0,2988	0,5861	0,1198	0,1278	0,5627
120	0,2316	0,1512	0,3648	0,3126	0,0431	0,2861
121	0,6914	0,6556	0,8091	0,4216	0,8098	0,7607
122	0,4544	0,5584	0,5824	0,2238	0,2294	0,6781
123	0,6833	0,7153	0,9575	0,6195	0,3533	0,7710
124	0,3142	0,2159	0,4654	0,1989	0,2592	0,4315
125	0,2544	0,1413	0,4359	0,1218	0,2214	0,3517
126	0,4345	0,4409	0,6190	0,1739	0,2565	0,6823
127	0,3880	0,3878	0,6850	0,2041	0,1891	0,4738
128	0,5103	0,2362	0,7785	0,3551	0,5738	0,6077
129	0,4167	0,4435	0,7549	0,2864	0,1699	0,4290
130	0,2800	0,2118	0,5833	0,1422	0,1145	0,3484
131	0,3887	0,4104	0,5161	0,3070	0,2482	0,4616
132	0,4660	0,4448	0,4384	0,3551	0,5857	0,5061
133	0,1900	0,1161	0,4842	0,0928	0,0252	0,2318
134	0,3412	0,2521	0,6447	0,1839	0,1555	0,4700
135	0,3267	0,3067	0,3582	0,1603	0,3509	0,4576
136	0,3876	0,3767	0,5534	0,3104	0,1812	0,5162

Plant	Russell Measure	Energy Cost Index	Labour Cost Index	Maintenance Cost Index	Waste Management Cost Index	Other Cost Index
137	0,4711	0,4643	0,6231	0,1226	0,5538	0,5915
138	0,3989	0,3794	0,5696	0,2180	0,1950	0,6324
139	0,3353	0,2540	0,5222	0,1913	0,1733	0,5359
140	0,4672	0,4772	0,7350	0,2594	0,3797	0,4848
141	0,1983	0,1624	0,2865	0,0879	0,1215	0,3333
142	0,4808	0,5327	0,8085	0,3266	0,1571	0,5789
143	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
144	0,4588	0,3959	0,8336	0,3061	0,1834	0,5750
145	0,2730	0,3015	0,3659	0,1591	0,1074	0,4310
146	0,4645	0,4446	0,6466	0,1492	0,5240	0,5582
147	0,2268	0,1684	0,3510	0,1013	0,2127	0,3008
148	0,5985	0,8788	0,5604	0,4335	0,4295	0,6904
149	0,5011	0,4872	0,7330	0,1116	0,6074	0,5665
150	0,3018	0,2655	0,4458	0,2726	0,1606	0,3646
151	0,2764	0,2282	0,4182	0,1022	0,2785	0,3551
152	0,2690	0,2969	0,4006	0,1377	0,1619	0,3479
153	0,8040	0,5801	1,0000	1,0000	0,4512	0,9886
154	0,6565	0,4068	0,8464	0,8954	0,6860	0,4477
155	0,3447	0,1580	0,4936	0,3555	0,3284	0,3881
156	0,5446	0,4605	0,5991	0,3117	0,7976	0,5539
157	0,4222	0,4159	0,9356	0,1982	0,1945	0,3667
158	0,5261	0,8720	0,5442	0,4300	0,1721	0,6121
159	0,4196	0,6418	0,4236	0,3288	0,2935	0,4104
160	0,4231	0,4433	0,2962	0,4789	0,4224	0,4748
161	0,8056	0,6260	0,8357	1,0000	0,6609	0,9052
162	0,3284	0,2828	0,4237	0,2788	0,2207	0,4360
163	0,2839	0,2677	0,4882	0,1592	0,1937	0,3108
164	0,3934	0,4139	0,5479	0,2774	0,2330	0,4947
165	0,3507	0,3214	0,5354	0,2594	0,1796	0,4577
166	0,2838	0,1341	0,5339	0,1825	0,1878	0,3806
167	0,4700	0,5861	0,4922	0,5468	0,2027	0,5222
168	0,6410	0,6584	0,5421	0,5644	0,8066	0,6334
169	0,4790	0,3683	0,5666	0,2240	0,6737	0,5622
170	0,6262	0,4174	1,0000	0,2287	0,6576	0,8273
171	0,2997	0,2736	0,3298	0,2782	0,2872	0,3298
172	0,2962	0,2599	0,3848	0,1970	0,2319	0,4074
173	0,1353	0,1261	0,1638	0,0760	0,0478	0,2626
174	0,0920	0,1350	0,1388	0,0492	0,0200	0,1172
175	0,5160	0,4613	0,7561	0,2799	0,4066	0,6759
176	0,5908	0,3567	0,7429	0,6112	0,4889	0,7542
177	0,3078	0,3630	0,3702	0,1114	0,2557	0,4387
178	0,3746	0,3229	0,4530	0,2290	0,4363	0,4318
179	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
180	0,4963	0,3963	0,7479	0,3441	0,5238	0,4694
181	0,4342	0,3645	0,5380	0,1557	0,6158	0,4971
182	0,5980	0,4620	0,6488	0,6320	0,6809	0,5661

Plant	Russell Measure	Energy Cost Index	Labour Cost Index	Maintenance Cost Index	Waste Management Cost Index	Other Cost Index
183	0,2071	0,2146	0,3236	0,0583	0,1503	0,2885
184	0,5198	0,4664	0,5696	0,4083	0,6058	0,5488
185	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
186	0,3554	0,3917	0,4037	0,4062	0,2314	0,3438
187	0,3682	0,5839	0,1931	0,4086	0,3970	0,2584
188	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
189	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
190	0,7567	0,5060	0,7611	1,0000	0,9616	0,5546
191	0,2790	0,2995	0,2419	0,3224	0,3423	0,1891
192	0,6628	0,5750	0,9629	0,4918	0,5704	0,7141
193	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
194	0,7075	0,7429	0,8621	0,4743	0,5890	0,8692
195	0,3337	0,4489	0,5223	0,2515	0,1721	0,2735
196	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
197	0,5110	0,5588	0,4675	0,3632	0,7663	0,3992
198	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
199	0,1242	0,0714	0,1882	0,1538	0,1155	0,0920
200	0,5058	0,7446	0,5852	0,3828	0,2612	0,5551
201	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
202	0,4834	0,5390	0,6437	0,3373	0,3465	0,5506
Mean	0,4423	0,4218	0,5550	0,3384	0,3354	0,5608

maintaining their output. The smaller plants show a significant inefficiency especially in terms of *Waste management cost*, *Energy cost* and *Maintenance cost* always in relation to larger plants (*Table 3*).

TABLE 3 Variance Analysis

Size of Plants (Cubic Meters)	Number of Plants	Russell Measure*	Energy Cost Index*	Labour Cost Index*	Maintenance Cost Index*	Waste Management Cost Index*	Other Costs Index*
Total Sample	202	0,4423	0,4218	0,5550	0,3384	0,3354	0,5608
< 50,000	52	0,4021	0,3405	0,5103	0,3031	0,2824	0,5743
50,000-100,000	44	0,4111	0,4312	0,5155	0,2813	0,2581	0,5693
100,000-250,000	51	0,4243	0,4051	0,5732	0,3025	0,2980	0,5428
250,000-500,000	33	0,4503	0,4214	0,5682	0,3622	0,3848	0,5147
> 500,000	22	0,6294	0,6350	0,6778	0,5839	0,6276	0,6227
Variance Analysis							
Statistic F		5,5776	7,0352	2,6651	6,1031	9,5009	1,0460
P-Value		0,0003	2,5848E-05	0,0337	0,0001	4,8165E-07	0,3847

* On average

Using these results as a basis (which verify the more efficient operations in larger plants compared to plants of a smaller size), we went on to calculate to what extent smaller plants could reduce their input expenditure if, given their vector of outputs, they operated with the same input efficiency as the group of larger plants. To do this we use the following expression,

$$\left(E_I^l - E_I^s\right) C_{mean}^s \tag{5}$$

where: E_I^l refers to the mean value of input efficiency for the largest plants; E_I^s symbolises the same indicator, but for smaller plants and, C_{mean}^s represents the average cost of inputs for the smallest plants. The result shows that, on average, the smallest plants could save a 34.5% in *Waste management cost*, a 29.5% in *Energy cost* and a 28.1% in *Maintenance cost*, for example, if they operated as efficiently as larger plants.

In short, according to the methodological approaches used herein, we verify the fact that the largest plants run more efficiently than smaller plants, as was showed in Hernandez and Sala (2005). At the same time, this more efficient performance is associated to the management of specific inputs such as *Waste management cost*, *Energy cost* and *Maintenance cost*. Finally, the benchmarking methodology based in non-radial measures is confirmed as a very useful management tool for the study of wastewater sector.

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JOINT OPTIMISATION OF SEWER SYSTEM AND TREATMENT PLANT CONTROL

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Abstract. Large cities in most of the cases are equipped with combined sewer systems discharging to waste water treatment plants. This is also the case for the City of Vienna. This city has just extended its Main Treatment Plant and has equipped the sewer system with a control system, which will make optimal use of the existing storage capacity, which amounts to about 500.000 m^3. For the operation of the treatment plant the worst loading situation occurs at the beginning of wet weather conditions. A sophisticated control system influencing the gates in the large trunk sewers and the control system at the treatment plant are aiming at minimizing the pollution discharge to the different receiving rivers and to optimize the treatment plant performance. The basic concept of the control systems is described and first operational results from the extended Main Treatment Plant of Vienna are presented in the paper.

Keywords: economic and ecologic considerations; point source abatement; urban waste water management.

1. Introduction

EU Water Framework Directive WFD (Council of the European Community, 2000) in conjunction with EU Urban Waste Water Directive UWWD (Council of the European Community, 1991) implies a combined approach for water quality management in urban areas. This means that there are minimum

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requirements for health protection (hygiene requirements) of the population, for flood protection in the settlement (EN 752) and for the protection of all receiving waters from point source pollution, i.e waste water treatment and CSO for combined systems and rain water discharge at separate sewer systems. For sewerage and waste water treatment EU-UWWD contains concrete definitions of the (actual) best available means for water protection with limited influence of the environmental conditions (less sensitive, normal and sensitive areas). For settlements with a population of less than 2000 inhabitants and for direct discharges of surface runoff and CSO national legislations have to fix minimum standards. This paper will concentrate only on settlements >2000 inhabitants.

The second important criterion for water protection technology is linked to the overall goal of WFD to achieve a good status of all receiving waters, which is defined verbally as “close to natural state”. Additionally there is a basic requirement to achieve the good status with a minimum of costs and there is also a clear indication in WFD that cost effectiveness of measures has to be considered carefully. This means that a status of water bodies which does not comply with all criteria for a good status can be maintained (at least for a limited period of time) if full compliance could only be achieved with excessive costs.

Cost analysis for the whole waste water infrastructure (sewerage and treatment) meeting the minimum legal requirements results in a cost structure where even more than 80% of the total yearly (capital+operational) costs are fixed costs. This means that they are not very sensitive in regard to drinking water consumption nor to waste water treatment efficiency requirements, but are mainly depending on the specific local situation (including climate). Also the risk which is mainly related to the frequency of non compliance can have some influence. For the consumers the costs are therefore mainly related to their right to discharge their waste water into the sewer system at any time during dry and wet weather. Peak flow and load conditions are the basis for the design of infrastructure and therefore mainly control the fixed costs while yearly water consumption or surface runoff have relatively little influence on costs but can be relevant for water protection.

As a consequence optimization of the waste water infrastructure in regard to costs and environmental impact will remain a difficult task. Even modelling of such systems becomes more and more elaborated. These mathematical models are based on the actual understanding of all the processes which are considered to be relevant for the solution of specific problems. They are one of the tools for decision making but cannot replace “political” decisions on all the relevant criteria. All the following considerations have to be evaluated under these boundary conditions.

2. Goals and Criteria for Optimisation

The basic goals of urban waste water infrastructure consisting of sewer system and treatment plant(s) are:

- protection of the population from diseases caused by contact with waste water
- protection from flooding of impervious areas (streets, etc.) and buildings
- protection of ground and receiving waters from pollution

It is common practice to define the minimum criteria for meeting these goals either by legal requirements and/or by state of the art documents, both representing the actual social consensus on a bearable risk taking into account sustainability criteria (resource management).

Optimisation can be defined as to meet these requirements at minimum costs. It seems to be obvious that optimisation should include the whole urban water infrastructure including water supply, waste water management and water protection (ground and surface waters). It is common practice to treat water infrastructure as a subsidiary aspect of city planning, while it is clear that the costs for construction and operation of water infrastructure are strongly influenced by city planning. This is appropriate for the specific length of water supply pipes and sewers depending on population density.

Traditional water supply and sewerage systems result in high investment costs. The total yearly costs decrease with an increasing life span of this infrastructure (50 to 150 years). The consequence of cost minimisation is that this infrastructure has long lasting influence on future urban development which is strongly influenced by existing traffic and water infrastructure. For urban settlements with low growth rate of the population, this is not a severe problem for the design of traditional centralised systems (small number of treatment plants). For fast growing large settlements, especially in the developing countries, alternative decentralised concepts have to be considered taking into account the specific local circumstances. These local circumstances include i.a. the historic development, climatic conditions, permeability of the soils, ground and surface water characteristics, availability of water resources.

As for all living systems, also for urban development the specific local limiting factors are of primary influence on optimisation. Water reuse is of primary interest where water availability, nutrient management and eutrophication abatement is a limiting factor etc. Actual costs do not adequately correlate with sustainability criteria. Nevertheless lowest costs are often also a good indicator for "sustainable" solutions.

Reliability of water infrastructure and water services represents an important cost factor. In regard to optimisation it therefore seems to be reasonable to find firstly consent on reliability criteria in close connection with economic and ecologic sustainability and secondly to try to minimise the costs afterwards. Otherwise cost comparison of different solutions does not provide a common basis.

If optimisation is defined as maximisation of cost efficiency (e.g. kg BOD removal/€) it turns out that in many cases no optimum can be achieved. Fenz (Fenz, 2002; Fenz and Kroiss, 2003) discusses the problem of setting minimum requirements for CSOs. All attempts to find a cost efficiency optimum fail for several reasons. The most important one is that increasing storage capacity for wet weather discharges results in an increasing retention of pollution from the receiving water. Increasing storage volumes result in decreasing cost efficiency, there is no optimum. The second point is that pollution loads from CSOs (containing raw sewage), from treatment plant effluents and diffused sources do not have comparable short and long term effects on the status of receiving water quality and there is no consent on how to make them comparable as this is a very complex issue (organic pollution versus heavy metals versus hygienic contamination). This example shows that optimisation process can only be successful if complex systems are simplified and a set of boundary conditions are fixed in advance.

3. Vienna Waste Water System as an Example for Optimisation

3.1. HISTORIC DEVELOPMENT

Vienna's sewer system dates back to the 19th century when the famous city planner Otto Wagner fixed also the waste water system. This plan was based on a forecast of a population of 3 Mio inhabitants. The city plan was strongly influenced by the heavily modified River Danube. The goal of the modification of the receiving waters in Vienna was to achieve flood protection and to gain large areas of highly valuable building grounds for the extension of the city. Danube wetlands were removed the Donaukanal and the new bed of Danube were created and River Wien was transformed to a concrete channel accompanied by two sewers the underground and important traffic roads.

Most of Vienna is equipped with a combined sewer system as the most densely populated part contributing to about 80% of the dry weather flow has impervious loamy soils. Only the most southern part drained by river Liesing has a separate sewer system, which is connected to the Blumental treatment plant for 150.000 p.e. This plant went into operation in 1969 and will be shut down by the end of 2005. It was one of the first large nutrient removal plants in Europe and worldwide (Matsché, 1972).

In the second half of the 20^{th} century flood protection was improved markedly by modifying River Danube a second time. “Danube” in Vienna now consists of two parallel beds. One is used for normal flow actually part of the hydropower plant “Freudenau”. The second (“New Danube”) is only used for discharge at high flow situations. Under normal flow conditions riverbed is equipped with two locks creating two consecutive lakes which represent the largest recreational area in Vienna for bathing and water sports. Due to these modifications a new trunk sewer had to be constructed on the left bank of New Danube collecting all the waste water coming from the left side of river Danube. In order to maintain bathing water quality combined sewer overflow was not allowed. The maximum capacity of this sewer (LDS) is 60 m^3/s.

This sewer construction was included in the “WABAS 80 plan ”(Vienna system for waste water management, 1980) for sewerage and waste water treatment, which was implemented to a large extent until 1980. In 1980 the Main Treatment Plant of Vienna (MTPV) went into operation. Already 1984 the first study regarding the possibilities to extend the MTPV was delivered by Vienna University of Technology (Emde, 1986). When the decision was made to build the extension of the MTPV to 4 Mio p.e. and to achieve nitrification and nutrient removal it was clear that this has to be complemented by a marked reduction of CSO discharge.

Vienna had a great number of CSO’s strongly contributing to river pollution. An early study on future CSO management recommended to build two or three storage tanks (total volume ~200.000m^3) close to MTPV in order to meet the requirements of best available means based on ATV (DWA) Guideline 128. Already WABAS 80 plan contained recommendations to create twin profiles for all trunk sewers so that repair and maintenance work will not any more result in raw waste water discharge to the receiving waters. The recently finished construction of a deep tunnel below Wien River WKSE (3.2 km long with a volume of 116.000 m^3) is one of the last projects within this plan.

3.2. CHARACTERISTICS OF THE VIENNA SEWER SYSTEM

Vienna has a population of ~ 1.6 Mio inhabitants of which 98% are connected to the sewer system. About 1.8 Mio inhabitants (including some neighbouring municipalities) are actually connected to the system and the actual pollution load discharged to the MTP is in the range of 3.2 Mio population equivalents (60g BOD_5/d).

The drained area is ~260km^2 , the “impervious” area about 125 km^2 or 12500 ha_{red}. This corresponds to a specific population density of ~130 inh./ha_{red}

(77 m^2/inh.).The length of the public sewers is ~2.220 km which corresponds to ~1.4 m/inhabitant, house connections not included.

The yearly runoff from impervious area is ~450 mm which is about 35m^3 of rainwater discharge to the sewer system per inhabitant and year. Yearly dry weather discharge to the Main Treatment Plant is ~ 125 m^3/inhabitant (including ~50% trade and industrial discharges). Rainwater only contributes to about one quarter of the total waste water flow in Vienna. This is a quite specific situation as compared to many small and medium sized settlements in Austria and Western Europe.

In 1997 the city parliament passed the new "Master Plan 2015" for waste water system development. This plan had become necessary to adapt to all the new legal requirements caused by EU directives (Council of the European Community, 2000 and Council of the European Community, 1991) and their consequences in Austrian water legislation. This plan included the construction of the extension of the MTPV, of several new trunk sewers and the development of a real time sewer control system which enables the use of the large storage volume of the sewer system for storm water management. Within the Master Plan it is assumed that the future impervious area can be reduced to ~8700 ha especially in the northern part of Vienna, where rain water can be infiltrated into the underground. This is not possible in the southern part where loamy soils prevail.

The development of this Master Plan was driven by the idea to optimise the whole waste water system, consisting of sewer system and waste water treatment both strongly influenced by the specific local situation. The latter includes the historic development (existing infrastructure), climate, future development (city planning) and restoration of surface water morphology.

With the Waste Water Master Plan 2015 (Smetacek, 2005a) it was decided to abandon the construction of storage tanks for CSO discharge control but to develop a control system making use of the large volume of the 5 large trunk sewers (>500.000 m^3). Fig. 1 and 2. show the two phases of the Real Time Control System implementation (Nowak and Flamisch, 2004) and the layout of the trunk sewers in Vienna.

The equipment of the sewer system with gates and the development of the real time control system will result in cost savings of about 77 Mio € as compared to the previously designed storage tanks of 250.000 m^3. In 2006 ~70% and in 2015 ~90% of the pollution discharged to the sewers will reach the MTPV for full biological treatment with nutrient removal (Smetacek, 2005).

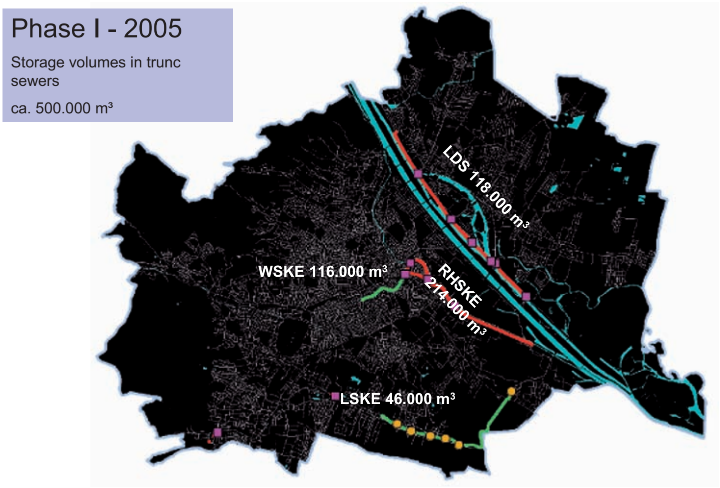


Figure 1 Storage volume in the trunk sewers activated by RTC system in 2006

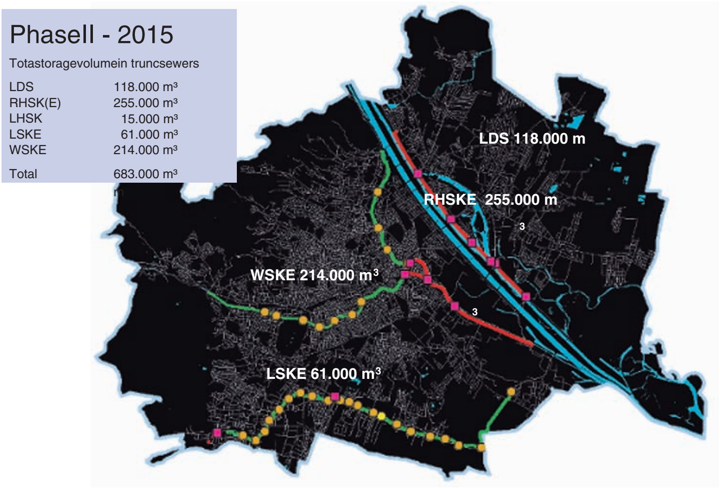


Figure 2 Storage volume in trunk sewers activated by RTC system in 2015

The project has two milestones, one by the end of 2005 (Fig. 1) together with the full operation of the extended MTPV and the second in 2015 (Fig. 2), when all the planned sewer constructions and also morphological changes for some of the small rivers will be finished (Smetacek, 2005a). Assuming that only half of the sewer volume can be effectively used for CSO reduction; the storage volume amounts to ~36m^3/ha$_{red}$ which is higher than the actual "best available technology" in Austria (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2001) and Germany (ATV Richtlinien für die Bemessung und Gestaltung von Regenentlastungsanlagen in Mischwasserkanälen, 1992). The optimisation criteria for the sewer control system have been (Nowak and Flamisch, 2004):

- Minimisation of CSO discharge to the rivers
- Equalisation of the loading of the MTP
- Improved sewer operation by sewer flushing in order to control sediment transport

4. Actual Situation at Main Treatment Plant of Vienna

4.1. DESIGN DATA AND PROCESS CONCEPT OF THE EXTENDED MTP

Figure 3 shows the layout of the extended plant. The biological treatment represents a newly developed two stage activated sludge nutrient removal plant. The old treatment in operation since 1980 is fully integrated as the first stage into the design concept without major changes (Kroiss et al., 2003).

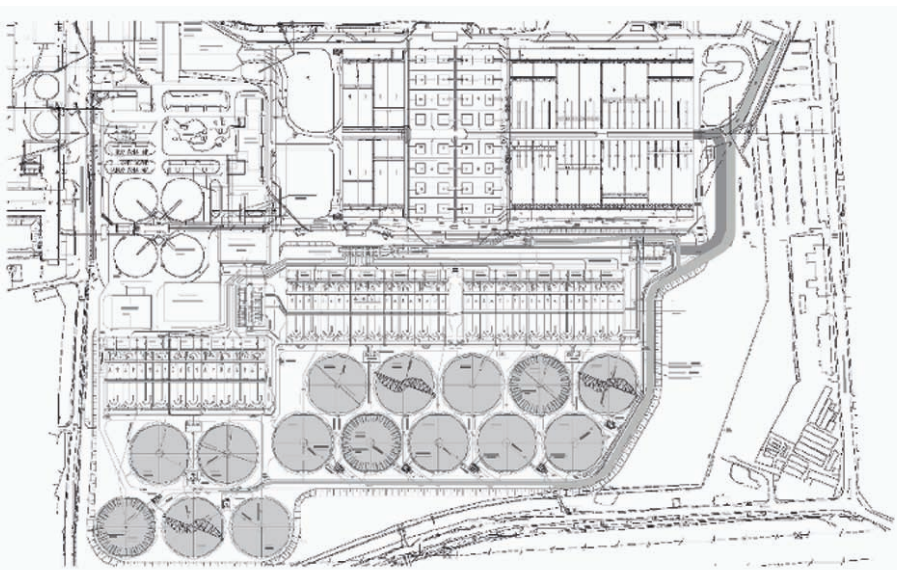


Figure 3 MTPV: existing plant (upper part) and plant extension (lower part, under construction) (Kroiss, 2003)

The construction of the second stage (Klager, 2005) was finished at the beginning of 2005 and went into full operation in June 2005. It consists of an activated sludge plant with 15 lines but only one activated sludge quality.

The design data and operational results of the old MTPV are summarized in Table 1 and basic design data for the newly extended MTPV in Table 2. Treatment efficiency requirements for the extended MTPV are shown in Table 3.

TABLE 1 Design data and operational results of the old MTPV

Design capacity	2.9 mio p.e. (60g BOD_5/d)
Max. design flow for primary treatment (wet weather):	24 m^3/s
Max. design flow for biological treatment	12 m^3/s
Actual mean dry weather flow	6 m^3/s
Volumetric BOD-loading rate	3 $kg/m^3/d$
Sludge age	~1.5 days
BOD reduction requirement	≥70 %
Real treatment efficiency for BOD removal	80-85%
TP effluent standard (since 2000 as yearly mean)	1 mgTP/l

TABLE 2 The basic design data for newly extended MTPV

Design load (2015)	4 Mio. p.e.
Mean dry weather flow	7 m^3/s
Design flow for dry weather (peak flow)	9 m^3/s
Max hydraulic capacity (wet weather)	18 m^3/s

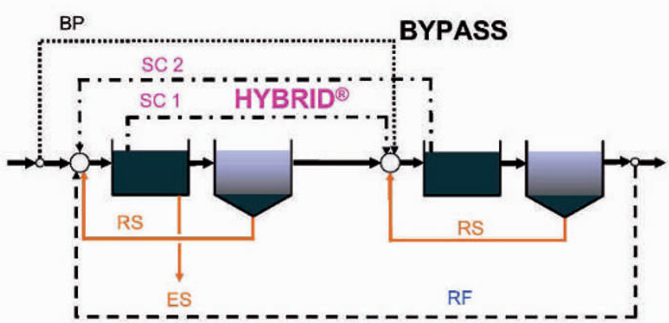
TABLE 3 Treatment efficiency standards for MTPV (Bundesministerium für Land- und Forstwirtschaft, Wasser und Umweltschutz, 1991)

Parameter	Dimension	95% ile	Maximum	Yearly mean
BOD_5	mg/l	15	30	
COD	mg/l	70	140	
NH_4-N (T>8°C)	mg/l	5	10	
Total N (T>12°C)	% removal			70
Total P	mg/l		2	1

As it can be derived from the design data the maximum hydraulic capacity of the mechanical treatment steps was reduced from the old plant to the new one from 24 m^3/s to 18 m^3/s which is a consequence of the joint optimisation of sewer system and treatment plant. At the same time the biological treatment capacity was increased from 12 to 18 m^3/s. This concept was based on a hydraulic modelling of the whole sewer system including the activation of the storage capacity described in the previous chapter.

The total specific aeration tank volume of the extended MTPV is only about 70 l/p.e. For a conventional single stage process design the required specific aeration tank volume would have been in the range of 150 – 200 l/p.e. Adding the specific intermediate sedimentation tank volume to the aeration tank volume results in ~85 l/p.e. which is about half of a one stage plant with the same treatment efficiency. It has to be mentioned that this two stage configuration requires more energy for pumping of the internal recirculation flows.

Figure 4 shows the two possible operation modes of this plant. Under normal operating conditions, the total excess sludge is always withdrawn from the first stage. The first stage is operated at a sludge age of about 1 to 4 days while in the second stage the sludge age is at about 8 to 10 days (Kroiss, 2003).



BP	Bypass line	SC 1	Sludge circulation line 1	RS	Return sludge
RF	Recirculation flow	SC 2	Sludge circulation line 2	ES	Excess sludge

Figure 4 Process scheme of the extended MTPV

The main challenge for two stage plants is nitrogen removal. At the extended MTPV nitrogen removal can be enhanced using two operational modes, the Bypass-mode and the Hybrid®-mode (Wandl et al., 2002) indicated in Figure 4.

In the Bypass-mode part of the primary effluent (BP) is bypassed directly to the second stage under all weather conditions. The bypass flow is operated within the range of 10 to 40 % of the total influent flow as carbon source for denitrification in the second stage.

In the Hybrid®-mode the whole primary effluent is fed to the first stage up to the maximum influent flow of ~11m^3/s (hydraulic capacity of the first stage), this corresponds with the operation of the old plant for the past 25 years. In the Hybrid®- mode the high loaded sludge from the first stage is used as a source of "oxygen" consumption for denitrification in the second stage (SC 1).

The excess sludge from the second stage is recirculated (SC 2) to the first stage in both operational modes enabling nitrification and denitrification also in the first stage. Sludge containing nitrifying bacteria from the second stage enters the first stage and thus enables nitrification in the first stage where the sludge age is too short for the accumulation of nitrifiers. The concentrations of BOD and ammonia in the first stage are at a level where nitrifiers and heterotrophic bacteria are close to their maximum growth rate.

Irrespective of the operational mode nitrate containing final clarifier effluent is recirculated (RF) to the influent of the first stage where sufficient substrate is constantly available to complete denitrification. The recirculation flow is adjusted automatically, so that the sum of incoming and recirculation flow remains constant (about 1.5 times dry weather peak flow). In this way there are no hydraulic load variations during dry weather which is very favourable for intermediate and final clarifier performance. Also wet weather flow results only in a relatively small increase of hydraulic loading to the final clarifiers.

In both operational modes the organic load transferred from the first to the second stage has to be controlled in order to maintain a sludge age sufficient for reliable full nitrification in the second stage. The higher the nitrification rate in the second stage, the more volume of the second stage can be used for denitrification. The second stage has to provide complete nitrification in order to maximise nitrification capacity needed to cope with ammonia peak loads (start of wet weather flow). Temperature as relevant parameter for nitrification rate has a high influence on the control strategy. As the mean temperature changes only slowly, the control of the sludge age in the second stage only needs rare decision making and manual control is enough. A specially adapted modified ASM 1 model is running in parallel to the full scale plant, so that the effect of foreseeable temperature development can be simulated before the control strategy is put into operation.

The optimisation of treatment plant operation is based on four hierarchic goals:

- Full nitrification at any time (and temperature) (normally NH_4-N<1mg/l)

- Maintenance of good sludge settling and thickening properties
- Denitrification as much as possible
- Minimisation of energy requirements

The second goal is mainly related to the two operational modes. Bypass mode results in higher nitrogen removal efficiency, for sludge thickening characteristics the hybrid mode is more favourable. The two last goals normally coincide.

5. Effect of Optimisation on Sewer and Treatment Operation

The following tables show the pollution load transferred to the River Danube at different stages of the historic development and the influence on the pollution concentrations.

TABLE 4 Daily pollution loads and maximum oxygen uptake along river Danube caused by pollution (Kroiss, 2005)

Parameter	Dim.	Daily pollution load to River Danube			Max. oxygen depletion in River Danube		
		without MTP	MTP I	actual	without MTP	MTP I 2004	MTP II 2005
BOD_5	Mg/d	200	36	7			
COD	Mg/d	370	90	26	360	80	16
TKN	Mg/d	33	18	1.2	140	78	5
NO_3 - N	Mg/d	0	0	6	0	0	(-17)
TP	Mg/d	6	0.8	0.6	-	-	-
Sum	Mg/d				500	158	24 (7)

Assuming a DO concentration of 10mg/l River Danube at Vienna has a maximum transport capacity for oxygen in the range of 560t/d during low flow. From Table 4 it can be concluded that without any waste water treatment the maximum oxygen depletion is in the same range. With the start of operation of the first MTPV in 1980 a great relief for water protection could be achieved, but there was still a noticeable influence. Since the extended MTPV (2005) is in operation a drop in oxygen concentration due to waste water discharge can hardly be measured any more.

Table 5 clearly shows that for several parameters in River Danube the increase in concentration due to waste water was quite relevant for meeting quality criteria while since the start up of the extended MTPV the increase in concentrations is in the range of the accuracy of monitoring procedures.

TABLE 5 Influence of Vienna waste water management on Danube pollution concentrations after complete mixing at low flow situation (Kroiss, 2005)

95% ile in stream concentrations				Increase of concentration		
Parameter	Dim.	Danube[+] upstream	LAWA[*] standard	Without MTPV	MTPV 2004	MTPV 2006
TN	**mg/l**	**3.0**	**3**	**0.3**	**0.16**	**0.07**
NO_3-N	mg/l	2,8	2.5	-	-	0.05
NO_2-N	mg/l	0.03	0.1	-	-	0.001
NH_4-N	**mg/l**	**0.15**	**0.3**	**0.3**	**0.14**	**0.03**
TP	mg/l	0.2	0.15	0.1	0.01	0.01
TOC	**mg/l**	**4.5**	**5**	**1**	**0.26**	**0.06**
O_2	**mg/l**	**10**	**6**	**-4**	**<-1**	**~0**

[+] Data from 2000 to 2004

[*] Standards for rivers with good status suggested by German Länder Working Group (LAWA, 1998)

6. Summary

Historic development and specific local situation plays an important role in combined optimisation of sewer system and waste water treatment. The situation in Vienna is characterised by the historic development of city planning in the 19th century and important modifications at the receiving waters for flood protection on the one hand and by rapid development of the legal requirements for water protection with special emphasis on EU legislation (Council of the European Community, 2000 and Council of the European Community, 1991) on the other hand. Another important aspect is the density of the population, the impermeable soils in large parts of the city and the relatively low yearly precipitation.

Two important Urban Water Management Plans (1980 and 2015) were implemented or are in the implementing phase which finally will lead to a good river quality not only for the large River Danube (mean flow ~1700 m^3/s) but also for the small receiving waters in the city, strongly suffering from CSO. The actual effort to use the existing or newly built trunk sewers for storage during rainwater by a real time control system has become a cornerstone for the combined optimisation of design and control strategy for the sewer system and the treatment plant.

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WASTEWATER TREATMENT IN BELARUS: PURIFICATION EFFICIENCY AND SURFACE WATER POLLUTION RISK

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Abstract. Official statistics were used for an investigation of wastewater disposal structure, for a study of characteristics of pollutants in urban sewage and estimation of anthropogenic (pollutant) load on receiving waters. The capacities of town sewage plants and efficiency of wastewater refinement are examined. It is shown that wastewater discharged without adequate treatment into surface waters has affected water bodies that have created some problems in water resources use. Pollution of receiving waters is analyzed.

Keywords: discharge; load; pollutant; purification; receiving waters; sewage disposal; wastewater treatment.

1. Introduction

Republic of Belarus (Belarus) is a medium size country situated in the center of Europe with a population of 9.8 million. It covers an area of 207,600 km^2 and borders on Poland, Lithuania, Latvia, Russia and Ukraine.

It is worth to mention that the territory of Belarus serves as the Main Watershed which separates the catchment areas of the Black and Baltic Seas. All large rivers of the country (the Dnieper, Zapadnaya Dvina, Neman, Vilia, Pripyat) are transboundary ones. The Dnieper empties into the Black Sea, while

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the Zapadnaya Dvina and Neman flow into the Baltic Sea. The Western Bug forms a state border between Belarus and Poland for 178 km length.

In the country the population is mainly and increasingly urban (up from 67 percent in 1991 to 70.2 percent as of January of 1, 2001). Minsk, the capital of Belarus, is situated on both sides of the Svisloch River (mean water flow – 40–50 m^3/s) and has an actual population of about 1.7 million. There are 5 other big cities (sizeable industrial centers) with a population of more than 250,000 (Gomel, Mogilev, Vitebsk, Grodno and Brest) which discharge their urban sewage into rivers. As a whole, there are 204 townships located in watersheds of 133 rivers that differ in dimensions. Urban growth within watersheds has resulted in intense pressure on water resources.

The greatest density of urban population (61.3 people per 1 km^2) is revealed in the Dnieper River catchment basin then follow the watershed basins of the Western Bug (40.3 people/km^2), Neman (28.4), Zapadnaya Dvina (12.2), and at last the Pripyat River watershed area (7.1 people/km^2). However, in small subwatersheds the density of urban population can range between 3 people/km^2 and 945 people/km^2 .

According to (Kadatsraya *et al.*, 2002), a density of urban population within a watershed can be regarded as a measure of its urbanization level and permits to make comparison catchment areas by a degree of anthropogenic (sewage) loads.

2. Wastewater Disposal

In Belarus the major part of generated wastewater (89–93 %) discharges into water bodies. The rest of wastewater amount is abstracted to storages, cavities, filtration fields, and aquifers (underground water). In 2004, total volume of sewage disposal into rivers amounted to 1138 million m^3 during the year and included wastewater of a different pollution level (State of Environment.., 2005). Starting from the quality, wastewater falls in three categories (type): normative pure wastewater (corresponding to legal standards without treatment), raw wastewater (insufficiently treated water), and normative treated water (corresponding to legal standards after purification).

In the country industrial water of cooling from works, urban runoff, and drainage-collector waters from irrigated and reclaimed areas are related to normative pure wastewater. They are discharged into the receiving waters without purification. At present the major volume of normative pure wastewater is generated by agriculture (156 million m^3), then follows industry (94 million m^3), and housing and communal facilities (11 million m^3). The amount of urban runoff and its chemical mixture, as a rule, does not take into consideration. In fact, in many towns snowmelt water and rainfall runoff from urban territories is transported via a stormwater sewer system to the receiving waters without treatment. But according to (Khomich *et al.*, 2003), in a large city urban runoff contains such pollutants as suspended solids, chlorides, natrium, nutrients, heavy metals and oil products. Raw wastewater is mainly discharged by municipal economy (88%). In 2004, they amounted to 11 million m^3 and their proportion did not exceed one per cent in total wastewater.

Table 1 presents the volumes of wastewater discharges into surface water bodies by a level of their purification.

For water emission, Table 1 gives some recent trends. Between 1990 and 2004 annual discharges of total wastewater continue to decline (they decreased by about 800 million m^3 in 2004 as compared with 1990), as do discharges that are regarded as raw (polluted) and normative pure. The latter has substantially decreased since 1990. The decline was caused by reduction of normative pure wastewater discharged by the fishing industry (reduction of 4.6 times or 60 percent of total reduction) and by the energy sector (reduction of 2.3 times or 24 percent of the total reduction). Discharges of raw (dirty) wastewater have decreased 9 times from 104 to 11 million m^3/per year. The amount of normative treated water did not exceed 866 million m^3 and its reduction was insignificant, as the greatest part of normative treated water (85 %) is domestic generated by municipal economy.

The reduction of wastewater discharges is largely the result of a decline in economic activity; little can be attributed to new investments in cleaner technologies or to the use of better waste minimization techniques.

TABLE 1 Wastewater discharges by a level of purification, million m^3.

Type of wastewater	Year						
	1990	1995	2000	2001	2002	2003	2004
Normative pure	959	424	265	279	265	256	261
Normative treated	919	841	883	903	884	872	866
Raw	104	64	25	23	20	15	11
Total	1982	1329	1173	1205	1169	1143	1138

3. Purification Efficiency of Wastewater Treatment

As is shown in the foregoing text, in cities of Belarus the most volume of sewage disposal is domestic wastewater produced by municipal facilities, and then follows industrial waste of which 83 per cent is generated by 18 large-scale enterprises. As is well known, industrial wastewater varies in composition from those similar to municipal sewage to those, which are more toxic, and contains a great variety of heavy metal. In spite of that fact, a number of works have discharged their sewage in a municipal sewerage system without preliminary treatment and they have been treated together with municipal wastewater in town sewage plants. Only 10 per cent of works have own (local) sewage plants in the country. However, after refinement on some local sewage plants wastewater has not met the requirements. Very often they contain supernormal concentrations of zinc (4.4–8.0 times more than a norm), nickel – 5 times, copper – 8.6 times, cadmium – 1.2 times, chrome – 70 times (Tatarinchik, 2001). Thus, town sewage plants accept wastewater with pollutant concentrations exceeding their designed values.

The greatest part of urban wastewater is subjected to mechanical then biological, and only partly physiochemical treatment. In the country the total capacity of all sewage plants is sufficient for treatment of overall annual wastewater volume. Between 2000 and 2004 their productive capacity has increased from 1329 million m^3 to 1351 million m^3 per year, while the actual volume of treated effluent has not exceeded 835 и 866 million m^3 per year correspondingly. But practically, many sewage plants accept sludge liquors with extremely high concentration of individual ingredients. Such heavily polluted wastewater can not be purified of undesirable chemicals completely. Also, in some townships treatment plants can not cope with the volume of received wastewater. At present there are 140 treatment plants per 204 cities and townships. Besides, in some treatment plants technical wear of cleaning facilities reaches up to 100%. Therefore, about 82–88 per cent of total volume of treated sewage contain pollutants exceeding standards. In large cities the same final effluent makes up 90–100% (Table 2).

TABLE 2 Wastewater emissions from point sources (State of Environment., 2003)

Point source	Wastewater discharge in rivers, million. m^3		Percentage of final effluent containing pollutants	Capacity of sewage plants, million m^3
	Total	Treated effluent containing pollutants		
Brest	48	48	100	50
Vitebsk	41	37	90	45
Gomel	65	65	100	74
Grodno	59	59	100	77
Minsk	268	260	97	298
Mogilev	59	59	100	103

Discharges of wastewater were analyzed from the standpoint of pressure formation on rivers in their watershed areas. The figure 1 shows the level of the load to water bodies caused by sewage disposal in main watersheds. The load coefficients are calculated as a ratio of annual volume of wastewater discharge to yearly water flow. The values received (0.01–0.04) are ranked in four levels of sewage load: weak (less than 0.01); medium (0.01–0.02); relatively high (0.02–0.03); high (more than 0.03) (Kadatskaya *et al.,* 2002).

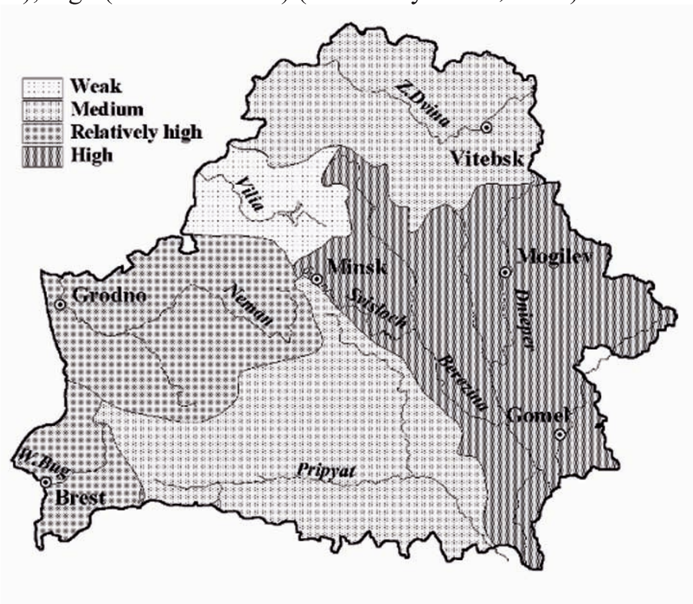

Figure 1 Level of anthropogenic loads to the catchment areas of main rivers of Belarus

As would be expected the greatest stress due to wastewater discharge has experienced the Dnieper River basin where sizeable industrial centers (Minsk, Gomel, and Mogilev) are situated. The highest level of urbanization has been determined there too (Kadatskaya *et al.,* 2002).

3.1. POLLUTANTS DISCHARGES INTO RECEIVING WATERS

Discharges of wastewater produced in main industrial centers of the country comprise 61% of all oil products amount, 54% of all ammonium nitrogen 54% of all BOD_5, and 54% of all heavy metal (Table 3).

In Belarus, according to data presented, the city of Minsk is the most powerful local source of anthropogenic stress by quantity of pollutant contained in wastewater discharges. One-forth of the total pollutant load is generated there. In 2004, the load accounted for 32 per cent of organic matter (3,112 tons), 37 per cent of oil products (59 tons), and 28 per cent of metals (123 tons) and had a pronounced effect on ecological state of the Svisloch River.

For pollutant amounts, Table 4 gives information on some recent trends. In general, the quantity of pollutants comprised in the wastewater remains practically the same by key ingredients for the past five years and their amounts have slightly been changed.

TABLE 3 Discharge of pollutants with final effluent into river (2004), tons per year

City	BOD_5	Oil products	Ammonium nitrogen	Sum of metals
Brest	382	10	364	21
Vitebsk	223	1	124	7.9
Gomel	509	7	81	27
Grodno	651	9	532	17
Minsk	3112	59	1786	123
Mogilev	254	12	290	31
Total in Belarus	9,600	160	5,900	454

TABLE 4 Volumes of chemical loads to surface waters, tons

Ingredient	Year				
	2000	2001	2002	2003	2004
BOD_5	10,600	9,700	8,900	8,500	9,700
Oil products	230	230	200	190	160
Suspended solids	14,800	15,100	13,200	13,400	13,400
Sulphate	64,000	63,100	62,700	68,400	64,000
Chloride	77,800	79,500	72,700	74,700	77,600
Ammonium nitrogen	6,600	7,200	6,300	6,200	5,900
Nitrite nitrogen	200	210	230	230	360
Nitrate nitrogen	2,700	3,100	2,800	2,800	3,800
Copper	18	21	13	13	15
Metals (iron, zinc, chrome, nickel)	491	521	435	418	454

As for the regional watersheds, the information on the quantity of some pollutants amounting to wastewater discharges is presented in Figure 2. The high ammonia nitrogen and heavy metals loads to surface waters in the Dniper River basin are evident.

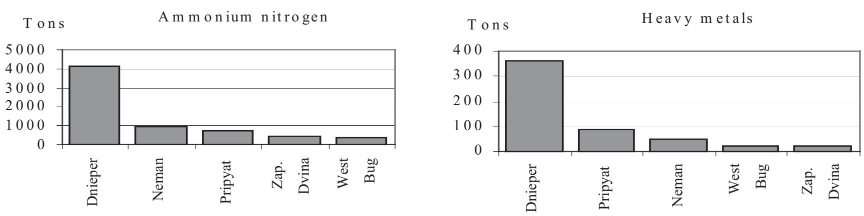

Figure 2 Chemical load to receiving waters in regional watersheds

Among the rivers in the Dnieper River basin, substantial contaminant loads due to wastewater pollutant experience: the Svisloch River, Berezina River, and Usa River below Gomel.

4. Quality of Surface Waters

Wastewater discharged without adequate treatment into surface waters has created serious problems that have affected aquatic ecosystems. In Belarus among the receiving waters, substantial contaminant loads due to wastewater pollutants experience: the Svisloch, Berezina, and Usa below Gomel in the Dnieper River basin, the Neman below Grodno, Zapadnaya Dvina below Novopolotsk, and Prypyat, below Mozyr. These and other rivers have no water resources sufficient for wastewater dilution to standards of fish farming (legal standards for surface waters quality). Surface waters quality is extensively monitoring in the country and is reported using water pollution index (WPI) which underlying parameters are: dissolved oxygen, BOD, ammonia and nitrate nitrogen, oil products and zinc. Based on WPI, water bodies are classified into seven categories: I – Clean; II – Relatively Clean; III – Moderately Polluted; IV – Polluted; V – Dirty; VI – Very Dirty, and VII – Extremely Dirty.

Now in Belarus the majority of rivers (57%) are classified as moderately polluted. In 2003, for instance, within the Dnieper River basin 15 per cent of water bodies were classified as relatively clean, 83 per cent – moderately polluted, and about 2 per cent – very dirty. In the Zapadnaya Dvina River basin the amount of moderately polluted rivers reached 54 per cent and relatively clean) 46 per cent.

The most polluted river is still the Svisloch at a section below sewage disposal of the Minsk aeration plant. It has been dirty for the last ten years.

Limiting indices of surface water pollution are ammonia nitrogen and nitrate nitrogen, oil products and zinc, phosphates, iron, copper, manganese, molybdenum and phenols.

The mean concentration of ammonia nitrogen in excess of the maximum permissible concentration (MPC) by 1.3–4.7 times is detected practically in water of major rivers of Belarus. Its maximum concentrations can reach up to 10 MPC in the water of Svisloch (The Dnieper River basin). Pollution of river water with nitrate nitrogen and oil products are less pronounced; the mean year concentrations are usually not over 0.2–4.4 and 0.6–3.4 MPC. However, the one-time (non-permanent) maximum concentration of nitrate nitrogen in water of rivers in the Dneiper basin sometimes reaches up to 10 MPC (the Svisloch) and 20 MPC (the Berezina). The one-time maximum concentration of oil products in river water does not exceed 4–6 MPC (National Report, 2002; State of Environment., 2004).

The mean year concentrations of zinc in water of the major rivers of the country are found out between 1.8–4.2 MPC and the one-time (non-permanent) maximum concentrations varies within 6.0–13.7 MPC.

5. Conclusions

The forthcoming quality of sewage has not resulted from waste treatment. Therefore, about 82–88 per cent of total volume of treated sewage contains pollutants (ammonium nitrogen, nitrite nitrogen, and heavy metals) exceeding standards. The case takes place for overload of municipal sewage plants, technical wear of their cleaning facilities and for lack of local treatment plants.

Industrial discharges into municipal wastewater system demand special attention, as industrial wastewater contains toxic organic substances or heavy metals that cannot be entirely treated in municipal wastewater treatment plants.

The discovered reduction of wastewater discharges (the volume of wastewater reduced more than trice as compared with 1995) is largely the result of a decline in economic activity; little can be attributed to new investments in cleaner technologies or to the use of better waste minimization techniques.

The results of river water quality monitoring evidence that in Belarus water of the majority of rivers is classified as moderately polluted.

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WASTEWATER TREATMENT AND REUSE

WATER REUSE IN CANADA: OPPORTUNITIES AND CHALLENGES

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Abstract. Reclamation and reuse of various types of wastewater, including stormwater, greywater, and domestic wastewater, represents an important component of the urban water cycle helping close the loop between water supply and wastewater disposal. Safe and scientifically-based water and wastewater reuse has been practised for about a century, and a great wealth of practical experience with such practices has been reported in the literature. Essential elements of water reuse plans include the selection of categories of reuse, selection of water quality criteria for such specific reuses (in accordance with the existing regulations and guidelines), design of the treatment train providing the effluent of the required quality, and examination of overall feasibility. In Canada, water reuse is generally conducted on a small-scale or experimental basis. While no national guidelines exist at this time, a number of provinces have developed guidelines for specific water reuse applications. The current stresses on water supply, caused by growing population and increasing water demands, depletion of water sources, reduced supply reliability caused by climate change, ageing infrastructure and limited funding for its expansion, as well as the promotion of environmental sustainability and needs to reduce wastewater discharges to sensitive receiving waters, will contribute to further growth and expansion of water and wastewater reclamation and reuse.

Keywords: Canada; guidelines; treatment; water quality criteria; water reuse; water reuse plans.

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1. Introduction

1.1. DEFINITIONS

Throughout this paper, the term *reclaimed water* refers to wastewater or stormwater that has been treated to a quality that is suitable for a given reuse application; and *water reuse* refers to the beneficial use of reclaimed water. *Water recycling* or recirculation typically refers to industrial systems, in which the effluent is recovered, usually treated and returned back into the industrial process. Wastewater reclamation and water reuse is conducted on various scales: from decentralized systems, utilizing on-site treatment and reuse in single buildings, to the municipal level, with centralized treatment and distributed reuse applications.

1.2. RATIONALE FOR WATER REUSE

There exists a continuous water management challenge worldwide to provide a balance between water demand, water use and the protection of water resources quality. On the whole, Canada enjoys relatively abundant and high-quality water supplies. Annual precipitation in Canada averages 600 millimetres, although it varies significantly by region (Statistics Canada, 2000). In fact, about 25% of municipalities with water supply systems reported water shortages during 2001, for reasons ranging from source water shortages to treatment and distribution system problems (Environment Canada, 2005). There are therefore areas with limited water supplies, particularly in periods of droughts and high water demands, and high consumptive use in agriculture. At the most recently reported level of 335 L/day (Environment Canada, 2005), per capita residential water use in Canada remains well above that in advanced west European countries.

Many municipalities are thus faced with the challenge of providing water supply to their growing population, in competition with other sectors of the economy and relying on finite supplies, and controlling wastewater discharge into receiving waters. Within the holistic concept of integrated water resource management, water reuse provides an opportunity to ease the current stresses on water supply, caused by increasing water demands, depletion of water sources, reduced supply reliability caused by climate change, ageing infrastructure and limited funding for its expansion. Water reuse simultaneously promotes environmental sustainability through conservation of water resources and reduces wastewater discharges to sensitive receiving waters.

2. International and Canadian Practice

2.1. INTERNATIONAL PRACTICE

Raw wastewater use for irrigation is still common in many low- and middle-income countries, although planned wastewater reclamation and water reuse is expanding in industrialised countries worldwide (U.S. EPA, 2004). The greatest water reuse occurs in regions suffering water scarcity, such as in the Middle East, the Mediterranean, Australia or the U.S. southwest. The field is also growing rapidly in regions with severe restrictions on effluent disposal, such as Florida, coastal areas of France, Spain and Italy, and densely populated countries, such as England and Germany (Lazarova *et al.,* 2001).

Globally, the most common applications of reclaimed water are in agricultural and landscape (particularly golf course) irrigation. In Japan, urban water reuse is also common, with 8% of total reclaimed water used for such purposes as car washing, urban water features, firefighting or toilet flushing (U.S. EPA, 2004). Other common water reuse applications include on-site residential / greywater reuse, industrial water recycling and reuse, rainwater and stormwater collection and reuse, surface water augmentation and groundwater recharge, and potable reuse. The various water reuse applications have been discussed by Exall (2004), and numerous case studies are described in the U.S. EPA's *Guidelines for Water Reuse* (U.S. EPA, 2004) and the report, *Water Recycling in Australia* (Radcliffe, 2004).

2.2. CANADIAN PRACTICE

Water reuse in Canada has to date been largely conducted on an experimental basis. Decentralized wastewater reclamation and water reuse is practised for individual homes and clusters of homes, or isolated industries, service operations and institutional facilities. Under such circumstances, the most common types of reuse are landscape irrigation and toilet flushing. The Canada Mortgage and Housing Corporation (CMHC) has been involved in numerous research projects regarding residential greywater reuse applications (e.g., Canadian Water and Wastewater Association, 2002; Waller *et al.,* 1998). Case studies of residential recycling and reuse in Canada include the Toronto Healthy House system, a four storey duplex built in 1996, and the CMHC Conservation Co-op in Ottawa, an eight-unit apartment complex. Both sites reported initial difficulties in maintaining water quality and required process adjustments after start-up. Greywater reuse systems have also been considered for areas in northern Canada to reduce dependence on trucked water supply and sewage disposal services (Waller *et al.,* 1998).

The main applications of centralized wastewater reclamation and distributed water reuse in Canada are agricultural irrigation, and golf course and urban landscape irrigation (Exall, 2004; CWRS, 1999). The practice of reclaimed water irrigation is quite well established in Western Canada, and experimental effluent irrigation projects have been conducted in Canada for over thirty years (Coote and Gregorich, 2000). Since 1977, the City of Vernon has operated a water reuse system for all effluent disposal, irrigating agricultural, silvicultural and recreational lands during the irrigation season of April to October. Such effluent irrigation projects must take into account water use, nutrient loading, salinity, and the presence and persistence of pathogens and trace contaminants.

Industrial water recycling is fairly common in Canada. Canadian industry accounts for over 80% of the total water intake, and of this total intake, approximately 40% is typically recycled. Many industries employ recirculation of their own process waters for use in such areas as cooling tower make-up water. The recirculation rate, defined as the volume of water recirculated as a percentage of total water intake, varies considerably by the manufacturing sector, from a low of 22% in the wood products group, to a high of 292% in plastic products (Scharf *et al.,* 2002). Other industries use reclaimed water as process water. In 2006, the City of Edmonton will begin supplying a local industrial partner with reclaimed municipal wastewater for use in hydrogen and steam production. As the water quality requirements for reuse can be specific to the industrial process and application of the water, advanced treatment systems are often required to produce water of acceptable chemical and microbiological quality.

Although results from a survey by the Canadian Water and Wastewater Association (2002) indicate that rainwater harvesting is rarely practised and almost never encouraged in Canada, stormwater reuse for golf course irrigation has been reported (Marsalek *et al.,* 2002). A recent workshop series held in six Canadian cities presented international rainwater harvesting practices and explored the potential for expanding its adoption in Canada (CMHC, 2005).

3. Opportunities and Challenges

The extent to which water reuse is adopted depends on water availability, economic incentives, regulatory feasibility, and public acceptance. Among these factors, water availability is probably the most important one; where water is scarce, water reuse is accepted by the general public, is economically feasible and a supportive regulatory environment is created.

In 2002, the Canadian Council of Ministers of the Environment (CCME) organized a national experts workshop on water reuse; a number of recommendations were made for further action in the areas of technology, policy and regulation, research, public acceptance, and coordination (Marsalek *et al.,* 2002). Much can be learned from the experience of other jurisdictions, as well. California's Recycled Water Task Force produced a report identifying twenty-six issues relating to obstacles, impediments and opportunities for increased recycled water usage in that state (State of California, 2003).

Careful planning is imperative in the implementation of new water reuse projects. Essential elements of water reuse plans include the selection of reuse applications, selection of water quality criteria (in accordance with the existing regulations and guidelines), design of the treatment train and infrastructure to store and convey the reclaimed water, and examination of overall feasibility. Common water reuse applications are listed above in Section 2.1; detailed descriptions of the categories can be found in the literature (e.g., Exall, 2004; U.S. EPA, 2004; Asano, 1998). The other elements of water reuse plans are discussed below.

3.1. WATER QUALITY CRITERIA

Once the reclaimed water source and applications have been determined, water quality criteria must be established, taking into account the protection of both public health and environment. The standards or guidelines that have been developed by various jurisdictions generally include reference to reclaimed water quality, wastewater treatment processes, treatment reliability, distribution systems, and use area controls. The removal of pathogens is typically the prime objective in treating wastewater for reuse, although the suitability of reclaimed water for such uses as food crop irrigation, industrial applications, and indirect potable reuse may be affected by such chemical constituents as biodegradable organics, recalcitrant organics, nutrients, heavy metals, residual chlorine and suspended solids (Crook, 1998). The removal of emerging trace contaminants such as endocrine disruptors and pharmaceutical residues is also of increasing concern (e.g., Khan *et al.,* 2004).

The State of California adopted the first reclamation and reuse standards in 1918 to address the use of reclaimed water for agricultural irrigation; these have been regularly updated and are used as a basis in the development of standards worldwide (Crook, 1998).

TABLE 1 Comparison of general characteristics of various water reuse guidelines and regulations

Jurisdiction		Applications considered	Minimum treatment recommended	Unrestricted irrigation coliform limit (per 100 mL)[a]
Canada	Alberta	Agricultural, landscape irrigation	Best practicable to achieve required quality	≤200 FC (geo. mean), ≤1000 TC (geo. mean)
	Atlantic Canada (4 provinces)	Agricultural, landscape irrigation	Secondary with six months storage	≤200 FC, ≤1000 TC
	Saskat-chewan	Agricultural, landscape irrigation	Secondary	≤200 FC (median), ≤400 FC (2 con-secutive samples)
	British Columbia	Agricultural, landscape, urban, industrial, environmental	Secondary with disinfection	≤2.2 FC (median), ≤14 FC (single sample)
U.S.A.	California legislation	Agric., landscape, urban, industrial, environmental, groundwater recharge	Secondary	≤2.2 TC (MPN), ≤23 TC (single sample)
	U.S. EPA (national guidelines)	Agric., landscape, urban, industrial, environmental, groundwater recharge, indirect potable	Secondary [b]	No detectable FC (median), ≤14 FC (single sample)
Inter-national	WHO guidelines	Agriculture, aquaculture	Secondary+ [c] or waste stabilization ponds	<200 FC

[a] FC = fecal coliform; TC = total coliform; MPN = most probable number

[b] Primary treatment for surface spreading for groundwater recharge only.

[c] Secondary treatment followed by filtration and disinfection or by polishing ponds.

Canada does not have national guidelines on water reuse at present, although guidelines for the reuse of household greywater for toilet flushing are currently under consideration by Health Canada. Guidelines have also been developed for specific uses by a number of provinces. The scope of applications, treatment and quality criteria in the provincial guidelines (Alberta Environment, 2000; CBCL Limited, 1996 [Atlantic Canada]; Saskatchewan Environment, 2004; BC MELP, 2001) are compared in Table 1 with those of the State of California (2001), the U.S. EPA (2004), and the World Health Organisation (WHO, 1989). While the recommendations for treatment are generally similar, the quality of water that is considered safe for unrestricted agricultural irrigation varies considerably by region.

3.2. TREATMENT, STORAGE AND DISTRIBUTION

The source of wastewater affects its level of contamination and the degree of treatment that must be employed to render the reclaimed water safe for the intended use. Numerous treatment technologies have been applied in water reclamation and reuse projects, and extensive reviews of such technologies can be found in Asano (1998) and Metcalf and Eddy (2003). The treatment processes applied at central facilities for wastewater reclamation and water reuse range from relatively low technology systems to advanced treatment systems. Many conventional treatment processes have been applied, including waste stabilization ponds, activated sludge, trickling filters, rotating biological contactors, filtration, and chlorination; the performance of many of these treatment technologies is relatively well known. Advanced wastewater treatment process combinations have also been applied in wastewater reclamation, including such membrane processes as membrane bioreactors and reverse osmosis, nutrient removal, and UV or ozone disinfection (Asano, 1998; Metcalf and Eddy, 2003).

For smaller on-site (or decentralized) systems, technologies exist and continue to be developed, although performance data are generally less well known and performance can be susceptible to upsets (e.g., influence of antiseptic and cleaning chemicals on small-scale biological treatment systems) (Marsalek *et al.*, 2002).

Storage system design requires consideration of evaporation and degradation of water quality by growth of microorganisms or pests such as mosquito populations, and odour problems; these may be controlled with appropriate management techniques or use of underground storage (Okun, 1997). Urban water reuse requires a dual distribution system, in which one system is used for potable water and a second for reclaimed water. The first dual distribution system in the U.S. was built in the 1920s to supply reclaimed water for landscape irrigation and toilet flushing in Grand Canyon Village in Arizona (Okun, 1997). Adequate labelling and signage of dual distribution systems is imperative and is often achieved through the use of coloured pipe or tape. Cross-connection controls and inspections are also essential in protecting public health (U.S. EPA, 2004). In Canada, standards on the design, installation, maintenance and testing of non-potable water systems using reclaimed water are currently in preparation by the Canadian Standards Association.

3.3. WATER REUSE PROJECT PLANNING

The overall project feasibility must be evaluated prior to initiating a wastewater reclamation and reuse project. Lazarova *et al.* (2001) discussed key economic, financial, regulatory, social and technical factors that contribute to the success of water reuse projects, and Mills and Asano (1998) described a planning analysis focusing on seven major feasibility criteria that should be considered:

- Engineering feasibility – includes considerations of water quality, public health protection, wastewater treatment and storage siting/design, and matching of supply and demand.
- Economic feasibility – the added treatment, distribution and storage costs for reclaimed water may be acceptable in urban, pollution-sensitive or water-scarce areas.
- Financial feasibility – issues of both financing construction/project implementation and generating revenue need to be addressed.
- Market feasibility – provides data needed to formulate project alternatives, including facility location, design criteria, and reclaimed water pricing.
- Institutional feasibility – involves the interaction of various institutions exerting influence at levels ranging from local to national.
- Environmental impact – water reuse projects change flows of water, wastewater and associated pollutants.
- Social impact and public acceptance – winning public support is of extreme importance in the case of water reclamation and reuse.

4. Conclusions

Despite abundant freshwater resources in Canada on the whole, there are regions where demand exceeds supply. Within the holistic concept of total water cycle management, one solution to the challenge is water reuse, which facilitates the use of treated municipal effluents as a new source for non-potable water supply. Reuse or recycling of treated wastewater reduces effluent discharges into receiving waters and offers a reliable alternative supply of water for applications that do not require high quality water, freeing up limited potable water resources. As compared to other countries worldwide, water reuse is currently practised infrequently in Canada, and usually is conducted on an experimental scale. In developing new water reuse projects, consideration must be given to project feasibility and planning, water quality criteria, and treatment and infrastructure needs. Guidelines and regulations dealing with water reuse projects exist around the world, and a number of Canadian provinces have recently produced guidance documents for water reuse applications. Various treatment technologies for on-site and central wastewater reclamation facilities are available and have been well described in the literature. As competing water demands increase and existing supplies are strained, expanded water reuse is likely. Critical evaluation of past projects and experiences in other areas of the world can provide needed insight for planning future applications of water reuse in Canada.

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INTEGRATED CONCEPTS FOR REUSE OF UPGRADED WASTEWATER – ROLE OF MEMBRANES IN WATER RECYCLING

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Abstract. The AQUAREC project on "Integrated Concepts for Reuse of Upgraded Wastewater" is funded by the European Commission within the 5th Framework Programme as well as in Australia by the Commonwealth Department of Education, Science and Training. The project is coordinated by RWTH Aachen University. The general objective of the AQUAREC project is to provide knowledge to support rational strategies for municipal wastewater reclamation and reuse as a major component of sustainable water management practices.

The project commenced in March 2003 and will be completed in February 2006. Treatment technology for water recycling encompasses a vast number of options and membrane processes are regarded as key elements of advanced wastewater reclamation and reuse schemes and are included in a number of prominent schemes world-wide, e.g. for artificial groundwater recharge, indirect potable reuse as well as for industrial process water production.

Membrane bioreactors (MBRs) are a promising process combination of activated sludge treatment and membrane filtration for biomass retention. The paper will briefly describe the AQUAREC project and depict the particular role of membrane processes in wastewater reclamation and reuse.

Keywords: wastewater reclamation, water reuse, water recycling, membranes.

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1. Introduction

Wastewater reuse presents a promising solution to the growing pressure on Europe's water resources. However, wastewater reuse implementation faces obstacles that include insufficient public acceptance, technical, economic and hygienic risks and further uncertainties caused by a lack of awareness, accepted standards, guidelines and uniform European legislation.

So far, there are no supra-national regulations on water reuse in Europe and further development is slowed by lack of widely accepted standards e.g. in terms of required water quality, treatment technology and distribution system design and operation. While guidelines for agricultural water reuse have been defined by the World Health Organisation, and by different states such as the USA and many Mediterranean countries, a uniform solution for Europe could provide a sound basis for further development of wastewater reclamation and reuse in many areas.

European standards have to take a complex water policy and management framework into account and have to balance the protection of water resources, economic and regional interests and consumer-related safety standards.

The general objective of the AQUAREC project is to provide knowledge for a rational strategy for municipal wastewater reclamation practices. The approach is interdisciplinary and broad, addressing issues of strategy, management and technology. The project aims to define criteria to assess the appropriateness of wastewater reuse concepts in particular cases and to identify the potential role of wastewater reuse in European water management.

The project will provide guidance for end-users facing decisions in the planning, implementation and operation of wastewater reuse schemes as well as for public institutions on various levels. By delivering a scientifically sound basis for further regulative measures, the project attempts to bridge the gap between research and water policy. Research activities in fields as broad as geography, psychology, marketing, chemical engineering and public hygiene are integrated and focused on wastewater reuse.

The AQUAREC project comprises nine different work packages which have all been active in the two years of the project and produced a set of preliminary results which provide the starting point to the provision of "best practice" recommendations and policy guidelines in wastewater reclamation and reuse of municipal wastewater treatment plant effluents in Europe.

Among those results are reviews of the water availability and demand situation on water stress situations. The state of wastewater reclamation and reuse application has been depicted by a comprehensive mapping activity, leading to an inventory of more than 3.000 wastewater reclamation facilities world-wide (Figure 1).

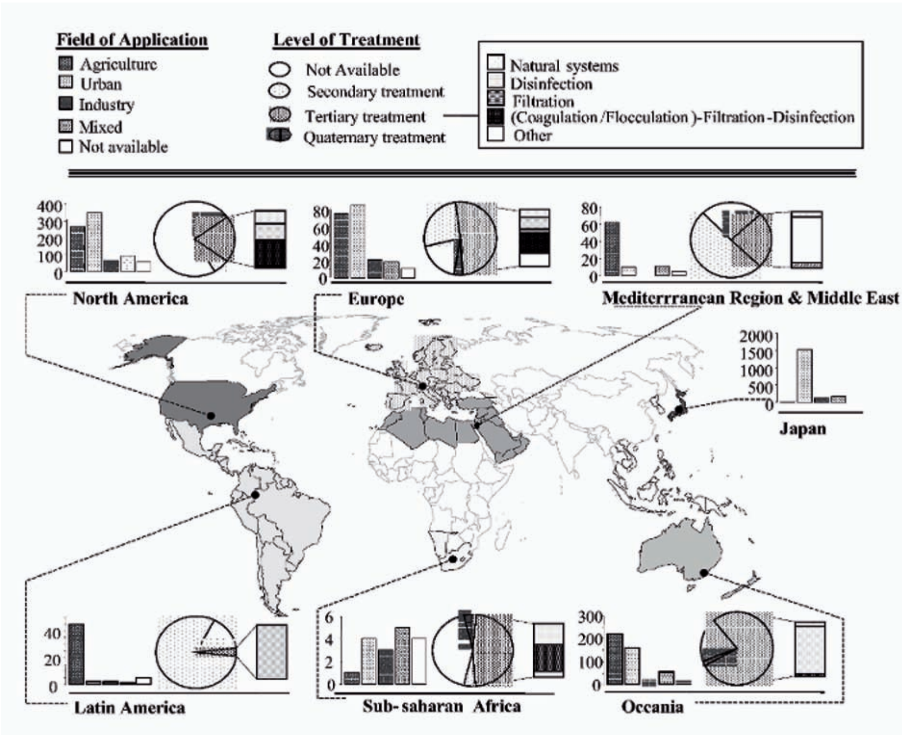

Figure 1 Water reuse schemes per field of application (bar-charts) and level of treatment (pie-charts with attached bar for main tertiary treatment processes) in different regions of the world (Bixio et al., 2004)

Based on the analysis of current wastewater reuse practice and the water management situation in all European countries a methodology for wastewater reuse potential estimation has been developed has been developed and employed. Simulation results indicate that wastewater reclamation and reuse will be able play a significant role in the water management of many European countries suffering now or in future of water stress.

Besides the Mediterranean countries which already practice wastewater reuse to a non-marginal degree a potential is likely arise also in some Eastern and Central European countries which face poor surface and ground water quality (e.g. Belgium and Bulgaria).

2. The Role of Membranes in Water Recycling

Membrane processes are regarded as key elements of advanced wastewater reclamation and reuse schemes and are implemented in a number of prominent schemes world-wide including artificial groundwater recharge, indirect potable reuse as well as industrial process water production.

Figure 2 Existing water reclamation schemes using membrane systems world-wide (Wintgens et al., 2004)

Figure 2 illustrates identifiable water reuse schemes using membrane technology world-wide (to date 27 full scale installations have been recorded). The schemes are divided per size and type of beneficial use. The map pictured in Figure 2 is destined to become outdated quickly. Many more projects are in an advanced planning phase. There is a clear trend for new larger scale plants to use dual membrane processes and MBRs.

As indicated in the previous chapter membrane processes are mostly applied as effluent polishing stages of municipal wastewater treatment plants, taking a secondary or tertiary effluent as feed with rather low suspended solids content.

An alternative to this "end-of-pipe" treatment is the application of MBRs as a straight combination of biological treatment processes and biomass retention by microfiltration (MF) or ultrafiltration (UF) membranes. MF and UF employed in tertiary wastewater treatment are dedicated to remove suspended solids, organic matter, and for disinfection, recovering a high quality final effluent with various possible uses. MF and UF technologies both in effluent filtration as well as in MBRs are also suitable as pretreatment to nanofiltration (NF) or reverse osmosis (RO).

Such physical barrier-processes are attractive in wastewater treatment because any technology employed must be able to produce reused water of uniform quality, regardless of the normally wide variation in the concentrations or physicochemical properties of the wastewater influent (Adin et al., 1998 and Alonso et al., 2002) and the absence of chemical addition is of economic and ecological benefit.

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WATER REUSE FEASIBILITY STUDY IN THE CZECH REPUBLIC

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Abstract. This paper describes the potential for greater wastewater reuse in the Czech Republic. On the basis of a country wide analysis of the water management situation, different regions were identified with particular water stress problems. The first water stressed region was identified on the basis of insufficient surface water quality, where most of the rivers were ranked into the water quality category V. This region is known as industrial area and hence there is a possibility to reuse wastewater for industrial purposes. The second investigated region is in a rain shadow area and can be characterized as water stressed in terms of climatic conditions. This area is in the South of Moravia which is famous for agricultural production, and there is a potential to reuse wastewater for agricultural purposes.

Keywords: wastewater reclamation, wastewater treatment, water reuse.

1. Introduction

Reliable water supply and the protection of aquatic resources through adequate water management are essential to support all aspects of human life.

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Wastewater from point sources - such as sewage treatment plants and industries can provide excellent reusable water because this water is usually available on a reliable basis, and has a known quality. Water reuse cannot only help to maintain downstream environmental quality and reducing the demand for fresh water sources, but can also offer communities an opportunity for pollution abatement by reducing effluent discharge to surface waters (Davis et al., 2003). A water reuse scheme is illustrated in Figure 1.

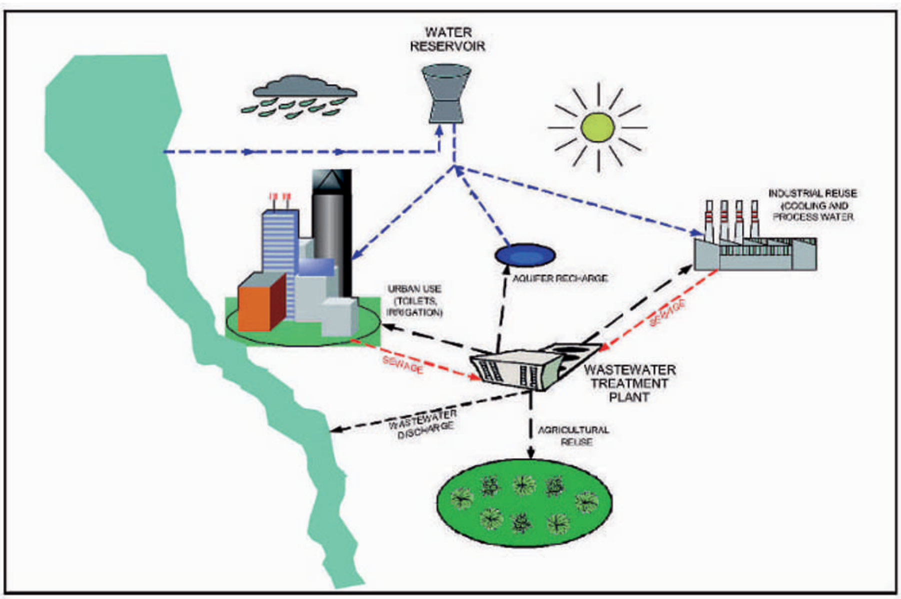


Figure 1 Water reuse scheme

Collection and treatment of wastewater as well as subsequent reclamation and reuse in one or more ways becomes a feasible method these days. Water reuse is an opportunity to shorten the hydrological cycle until the water is used again and can be utilised when it offers sufficient environmental, social, economic and political benefits (Water Corporation Perth, 2004).

Policies of creating public awareness and of putting in place the necessary infrastructure to treat water and dispose of wastewater is essential to reduce the pressure on the environment. Wastewater reuse is a potentially viable component of integrated water resources management along with demand and supply side management. Water reuse can help to maximize the use of limited water resources and can contribute to economic development (Chu et al., 2004).

This paper gives an example of feasibility study in the Czech Republic concerning climatic, water quality and environmental impacts and offers some possibilities for water reuse application in the Moravia region.

2. Feasibility Study in the Czech Republic

2.1. CZECH REPUBLIC CHARACTERIZATION

The Czech Republic is a landlocked state lying in the centre of Europe. The amount of precipitation in the Czech Republic is usually being compared to the long-term average from 1961-1990. The total rainfall in the year 2003 was 516 mm, which is only 77% of the long-term average. The Northwest area and the Moravia region had less then 500 mm of precipitation in 2003 (Czech Hydrometeorological Institut, 2004). Some parts of the Czech Republic area can be consider as temporarily water stressed, particularly considering the pressures on the surface water as discussed later.

2.1.1. *Water resources*

The hydrogeological conditions of the Czech Republic differ greatly on a regional scale. Significant useable sources of ground water are delimited by the rocks of the upper cretaceous and quaternary fluvial sediments. These sources are suitable for the supply of drinking water in some regions but most water supplies in the Czech Republic depend almost exclusively on atmospheric precipitation. Its annual amount reaches a long-term average of 16,700,000,000 m^3, which represents 1,621 m^3 per person and which is approximately half of the European average. Surface water, of which two-thirds are taken from reservoirs and rivers, is used for the production of drinking water to the extent of 55% (Ministry of Agriculture, 2002).

There are also some dry areas in the Czech Republic (Figure 2). Dry areas in the Czech Republic are defined as areas belonging to dry climatic regions or where soil has a low water-holding capacity. These areas are mostly in regions of the rain shadow of Krusne hory and in South Moravia. There are 270,000 ha defined as dry areas (Ministry of Agriculture, 2004).

2.1.2. *Abstractions of surface and ground water*

In the last decades, the abstraction of surface water has been on a decreasing trend. In the year 2002 in the Czech Republic a total of 1,309,800,000 m^3 of surface water was abstracted, of which 395,800,000 m^3 was for the purposes of the public water supply, 11,300,000 m^3 for agriculture, 619,700,000 m^3 for electricity generation, 338,700,000 m^3 for industry, and 2,500,000 m^3 for other purposes. In the category of abstractions for agriculture there was an increase by 65.2% since 2002. The category of abstractions for water supply systems was virtually stagnant.

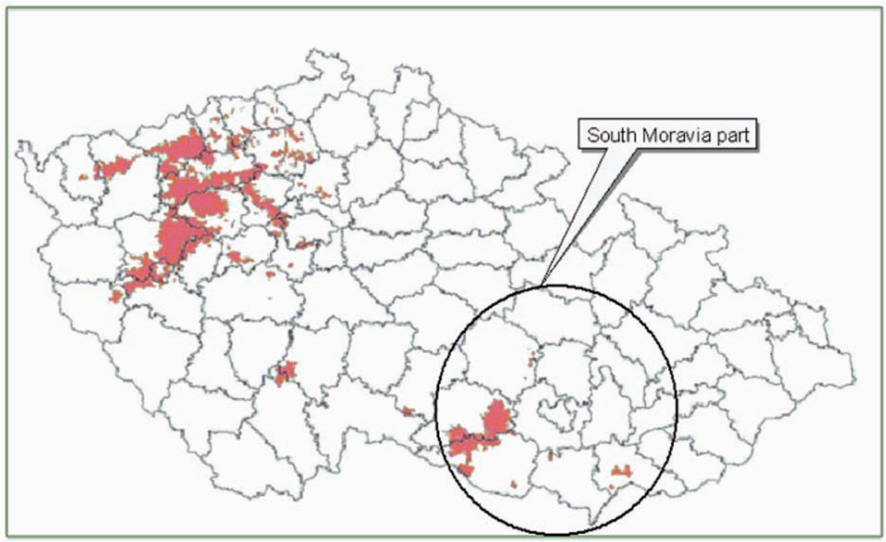


Figure 2 Dry areas in the Czech Republic (Czech Hydrometeorological Institut, 2003)

Abstractions in the category of water supply systems for public use accounted for 86.9% of total abstractions of groundwater. Average abstraction of ground water for public water supply from 1980 to 2003 is 45,000,000 m^3 and also has a decreasing trend (Ministry of Agriculture, 2002).

2.1.3. *Water for irrigation purposes*

Irrigation is not a very significant type of water consumption in the Czech Republic because the area equipped with irrigation systems covers only approximately 125,000 ha out of 42,798,876 ha of agricultural land. One traditional area for irrigation is the Znojmo area, where irrigation systems have been built on approximately 21,000 ha.

2.1.4. *Quality of surface and ground water*

In the course of the period 1991 – 2002 (Figure 3) there was a changeover from class V to class IV (heavily polluted water) and to class III (polluted water) in almost all rivers in the Czech Republic.

The long-term improvement in water quality was primarily due to the construction or intensification of decisive wastewater treatment plants and by the halting or limiting the production of many industrial enterprises and a reduction in the use of fertilisers in agriculture. The worst surface water quality was recorded on three rivers: Trkmanka, Litava and Kyjovka affected by industrial wastewater.

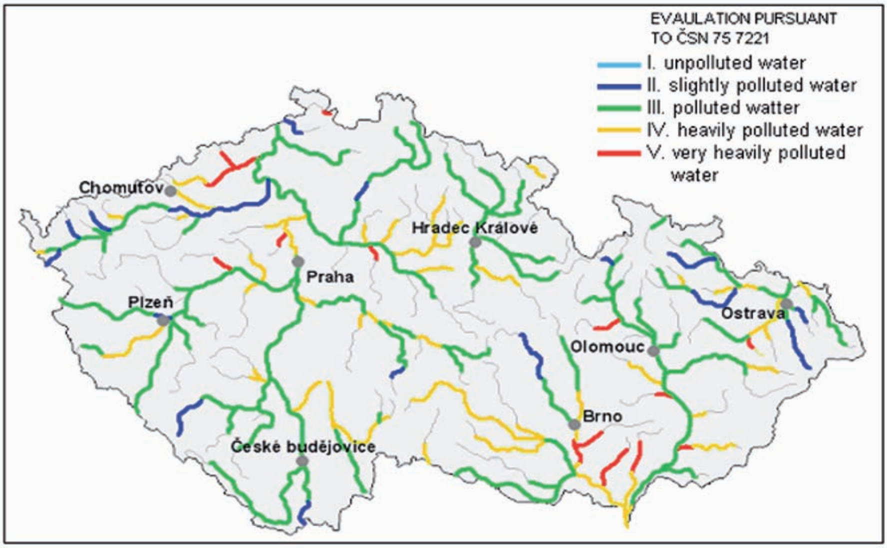


Figure 3 Quality of water in watercourses of the Czech Republic 2001 – 2002 (Ministry of Environmental, 2004)

The quality of groundwater has not changed significantly in recent years. A comparison with 2001 has demonstrated that there was a slight improvement in the shallow wells, whereas there was a slight deterioration in deep wells and springs (Ministry of Agriculture, 2002).

2.1.5. *Water reuse options*

The source of wastewater can vary from industrial discharges to urban effluent. The treated wastewater can be used for a range of purposes, from such high-quality uses as indirect potable use to lower quality requirements such as water for agricultural or industrial purposes or for toilet flushing and cooling water (Davis et al., 2003). Wastewater can be used for any purposes as long as adequate treatment is provided to meet the water quality requirements for the intended use.

Favourable conditions for wastewater reuse for industrial and agricultural purposes can be located in the South Moravia area. Industrial reuse of wastewater could cover mainly cooling, process water, washing and rinsing utilizations, for agriculture it could be used mainly for crop irrigation purposes.

2.1.6. *Industrial reuse*

From the regional point of view there is a need to specify the main industrial enterprises which use water on a large scale for cooling or some other industrial purposes and could utilise reclaimed water.

In terms of water quality in the Moravia area, the Kyjovka, Trnkmanka and Litava rivers were ranked into the class V. water quality category (Ministry of Environmental, 2004). Six companies in Kyjov were identified as potential users of reclaimed wastewater. These companies are the biggest surface water contaminators in the whole Moravia area and offer good possibilities for water reuse application.

To date 12,500 inhabitants live in the Kyjov industrial zone. This area is Southeast of the Brno district, the capital of Moravia. Nowadays, Kyjov is the centre of glassmaking industry and as a community with extended activities, a partner of another 41 villages in the whole Kyjov urban area (Kyjov, 2004).

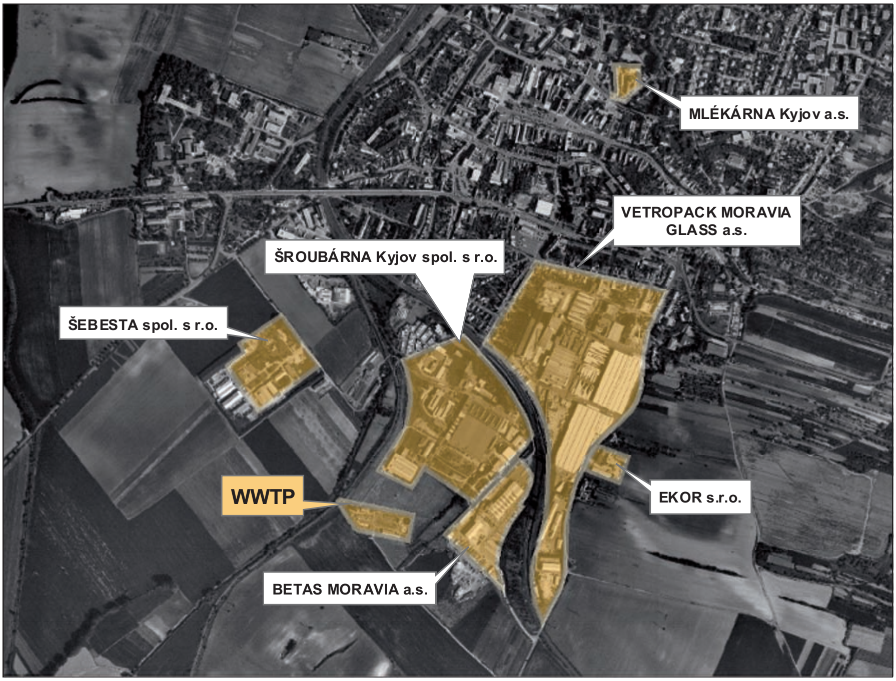


Figure 4 Industrial zone in Kyjov (Geodis Brno, 2004)

The Kyjov district varies greatly in terms of industry but the majority has a metal and glass industry. The range is represented by the following enterprises (Figure 4):

- VETROPACK MORAVIA GLASS a.s. – producer of packaging glasses for food industry,
- SROUBARNA Kyjov spol. s r.o. – producer of connecting materials,
- MLEKARNA Kyjov, a.s. – dairy works,
- SEBESTA spol. s.r.o. – producer and distributor technology for WWTPs and car washrooms,
- KM BETA a.s. – producer of roofing,
- EKOR s.r.o. – treatment of waste, waste disposal, technical services.

Wastewater treatment plant in Kyjov

The wastewater treatment plant (WWTP) in Kyjov was brought into operation in 1996. This WWTP is a mechanical-biological treatment plant with aerobic stabilisation of sludge. Collected sewage is pre-treated (bar screen, mechanical fine screen, grit chamber). Another operational complex forms a biological treatment stage, which includes a circulating activation tank, secondary settling tanks, and a pumping station for re-circulated and excess sludge.

The number of people living in Kyjov and in the surrounding area is 18,000. The wastewater flow rate is dimensioned for 26,335 Inhabitant Equivalent (Table 1) (Aquatis Brno, 2003).

TABLE 1 WWTP loading (Aquatis Brno, 2003)

Consumption of water	140	l / inhab.day
Pollution:	60	g BOD_5 / inhab.day
	120	g COD / inhab.day
	12	g N / inhab.day
	2	g P / inhab.day
Incoming BOD_5	1293	kg / day
TSS	1508.5	kg / day
N	189	kg / day
P	40	kg / day

The previously named enterprises use a large amount of water for their various industrial purposes (Table 2). This water has not a high quality category and hence there is an opportunity to use treated wastewater from the WWTP in Kyjov for such industrial purposes.

TABLE 2 Water demand for selected companies

Company	Water demand [m3/day]
Sebesta spol. s r.o.	22,67
KM Beta a.s.	34,79
Sroubarna Kyjov spol. s r.o	122,48
EKOR s.r.o	8,88
Mlekarna Kyjov, a.s.	73,59
Vetropack Moravia Glass a.s	297,09
Total	559,5

2.1.7. *Agricultural reuse*

Agricultural reuse has sound environmental benefits, because it can also improve the nutrient balance of under-utilised land.

From climatic conditions shown on the dry area map in the Czech Republic (Figure 2), it is obvious that there are some dry places in South Moravia. This area is also known as an agricultural area where a large irrigation system has been built. A large amount of water is used for irrigation purposes mainly for wine and vegetable production and for fruit growing. In terms of this study, the Znojmo area has been identified as a potential region for agricultural water reuse application.

Znojmo has about 40,000 inhabitants and in the surrounding area live approximately 60,000 inhabitants. Favourable elevation above the see level (289 m) and suitable climatic conditions make this area suitable for agricultural purposes. The city is also a centre of a famous viticulture region, being surrounded by fertile vineyards producing fabulous wine. The Znojmo wine district is one of the largest wine districts in Moravia, which includes 76 vine-growing communities (Znojmo, 2004).

Agricultural land area represents a total of 163,678 ha. Arable land is about 103,909 ha.

The VaK Znojmo Company deals with the ground water system and the sewage disposal. This organization in the Znojmo urban area contains 74 participants and is responsible for water and wastewater management for whole Znojemsko area. The main objective of their work is to preserve the quality of potable water and wastewater as well as to manage the operation of the Znojmo wastewater treatment plant. Table 3 summarises the main indicators of water availability in Znojemsko region (Ministry of Agriculture, 2002).

TABLE 3 Water availability and abstraction in the Znojemsko region in 2003 (Ministry of Environmental, 2004)

Surface water	4,054	10^3 m^3 / year
Ground water	-	10^3 m^3 / year
Number of water reservoirs	4	
Produced water	3,930	10^3 m^3 / year
Average water loss	1,321	10^3 m^3 / year
Intake of water for domestic consumption	1,563	10^3 m^3 / year
Intake of water for industry	1,046	10^3 m^3 / year
Intake of water for agriculture	not observed	10^3 m^3 / year

Wastewater treatment plant Znojmo

The original wastewater treatment plant in Znojmo was constructed in the 1970´s. A complex upgrading of the Znojmo WWTP was undertaken between the years 1996-1999. Funding of these works was provided by the Environmental Fund of the Czech Republic, a grant from EU Phare funds allocated by the Austrian government for environmental support abroad, and by the project investor ZSO VaK Znojemsko (Znojmo, 2004).

The wastewater conveyed to the plant is first disposed of grit impurities on the water line using fine screens. Sand and floating matters are than trapped in a centrifugal sand trap and grease trap. The original biological stage (activation tanks, secondary clarifiers) has been fully replaced by the new biological treatment, employing the principle of interrupted cyclic activation of sludge. All the upgrading was carried out during full operation of the original WWTP (Wastewater Corporation in Znojmo, 2004).

The wastewater treatment plant is dimensioned for 99,000 PE (People Equivalent). Average discharge is 10,000 m^3/day (55% of capacity), capacity discharge is 500 l/s. The main wastewater indicators are listed in table 4.

TABLE 4 Average values from outlet of the WWTP in the Znojmo city (Wastewater Corporation in Znojmo, 2004)

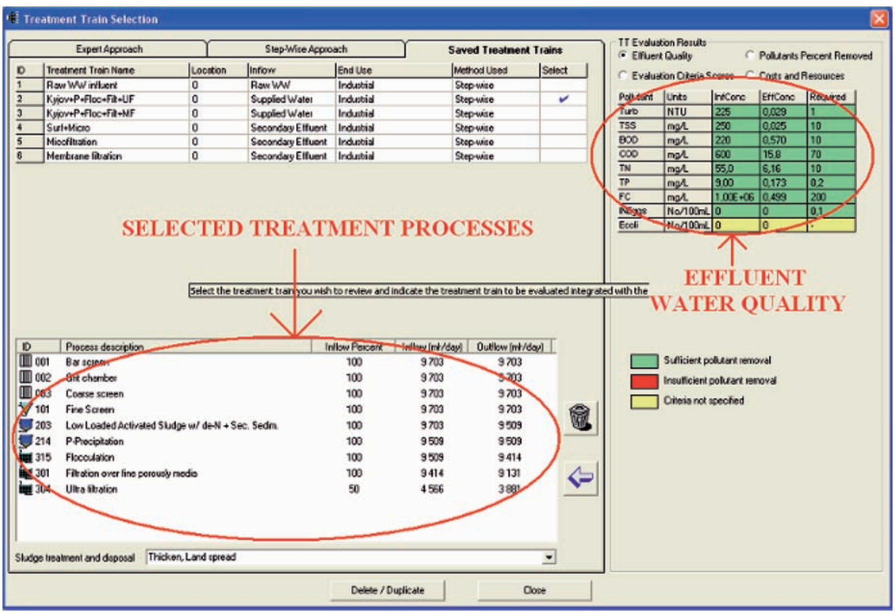
Indicator	Value	Unit
COD	33.3	mg/L
BOD_5	4.7	mg/L
TSS	7.4	mg/L
P_{total}	0.3	mg/L
NH_4^+ - N	3.3	mg/L
NO_3^- - N	3.6	mg/L

Water reclamation could involve recovering treated wastewater from the Znojmo municipal wastewater system. Treated wastewater could be used for a large range of activities in country areas including: irrigation of agricultural fields (parks, gardens) or irrigation of vineyards.

3. Example of Proposed System in Kyjov

Within the AQUAREC project there were developed software WTRNet where different treatment technologies could be selected by end-users. In Kyjov WWTP primary (bar screen, grit chamber, coarse screen, fine screen) and secondary (low loaded activated sludge w/o de-N + secondary sedimentation) treatment stage already exist but has insufficient effluent water quality. Therefore several proposed systems could be designed (Figure 5). WTRNet Software is evaluating effluent water quality as soon as the treatment technology is selected.

Figure 5 WTR Net software (Aquarec project)



To obtain required water quality for industrial purposes there were designed first proposed system (Table 5) with the calculation of the cost for the selected treatment technologies.

TABLE 5 First proposed reuse system in Kyjov and its cost in EUR.

Treatment process	Construction cost	Annual O&M cost	Land costs
Bar screen	344 200	31 300	48,7
Grit chamber	393 400	39 300	44
Coarse screen	551 100	55 100	48,7
Fine screen	1 046 700	52 300	20,7
High loaded activated sludge + Sec.sedimentation	2 779 300	259 900	860,3
P-Precipitation	38 800	14 800	75,0
Filtration over fine porously media	601 900	31 800	3 347,4
Nanofiltration 10%	274 100	37 000	25,7
Total	6 029 500	521 500	4 470,9

Overall cost includes also costs connected to the distribution, site and other cost. Total treatment cost for the first proposed system was calculated as 18,291,970 EUR what represent 1,713,570 EUR of total treatment annual costs.

4. Conclusion and Next Steps

During the Czech Republic analysis on the basis of climatic conditions and surface water quality considerations two regions were identified which have a good potential for wastewater reuse application.

The first identified region is located in South Moravia in Kyjov city, which has poor surface water conditions, with most of the rivers being ranked into the class V water quality category. The worst situation is evident on the Kyjovka, Trnkmanka and Litava rivers. While Kyjovka river pollution is mainly affected by the industrial zone in the south of Kyjov city six companies were identified where industrial wastewater could be reused. For these purposes, the wastewater treatment plant in Kyjov could be utilized and developed WTRNet software could be used. WTRNet Software is evaluating effluent water quality and the treatment price as soon as the treatment technology is selected.

The second selected region is also in South Moravia but in the Znojmo area, which can be characterised as water stressed in terms of climatic conditions. This area is characterised by its low precipitation, being in the South Moravia rain shadow. The Znojmo area is very well known as an agricultural area with a large irrigation system. An alternative source of water, reclaimed wastewater from the wastewater treatment plant in Znojmo, was identified. Reclaimed wastewater from the Znojmo WWTP could be used for crop or vineyard irrigation in the surrounding agricultural area.

The next steps within the AQUAREC project will be in the first case (Industrial reuse) to evaluate several WTRNet designed treatment processes and to introduce the system to the potential end-users in the Kyjov city. Local stakeholders will be involved as they will have a crucial role in defining and implementing any water reuse projects.

In the second case (agricultural reuse) there is need to obtain several data to run the WTRNet software which will work on a similar basis as in the first case.

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ALTERNATIVE FORMULATIONS FOR THE REUSE OF TREATED WASTEWATER IN MENEMEN PLAIN IRRIGATION SCHEME

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Abstract. In this study, it is intended to investigate the possibility and technical viability of using the effluents of Izmir Wastewater Treatment Plant in Menemen plain irrigation. The research verified the fact that the influent of the plant generally demonstrates typical characteristics of domestic wastewater with the exception of elevated values of electrical conductivity and salinity. These high values are mainly attributed not only to salt water intrusion due to failing pipes and improper pipe connections of the interceptor canal but also to highly-concentrated pre-treated discharges of various industries within the city. It has also been observed that these high values are as well reflected in the plant effluent hindering its use in irrigation. Considering the strong demand for the treatment plant effluent by the farmers and irrigation unions, this study intends to find out possible solutions for high conductivity and salinity. The research involves the formulation of alternative techniques and methodologies such that the quality of treated effluents would satisfy the irrigation water quality criteria currently effective in Turkish legislation.

Keywords: wastewater reuse; irrigation; Menemen plain; Izmir.

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1. Introduction

The city of Izmir is one of the largest metropolitan areas of Turkey with a total population of about 3.5 million. It is also a busy commercial and industrial center and a gateway between the Aegean and Central Anatolia. Currently, the city is the biggest import/export port of the country. Being situated in a semi-arid region that is governed by typical Mediterranean climate (i.e., hot dry summers and warm wet winters), the city of Izmir experiences severe droughts that restrict the amount of water applied to the agricultural fields for irrigation. Water use restrictions are frequently implemented during summer months resulting in severe reductions in agricultural production.

The Menemen plain that is located at the most downstream portion of the Gediz River basin and formed by the fertile alluvial deposits of the river is one such area in the immediate vicinity of the city of Izmir (Figure 1). The limited amounts of irrigation water supplied to the plain from the most downstream reaches of Gediz River is heavily polluted due to uncontrolled raw domestic and industrial wastewater discharges as well as agricultural return flows from upstream farming practices. Nevertheless, the irrigation unions and individual farmers of the region are desperate for water and eager to accept any quality water offered to them.

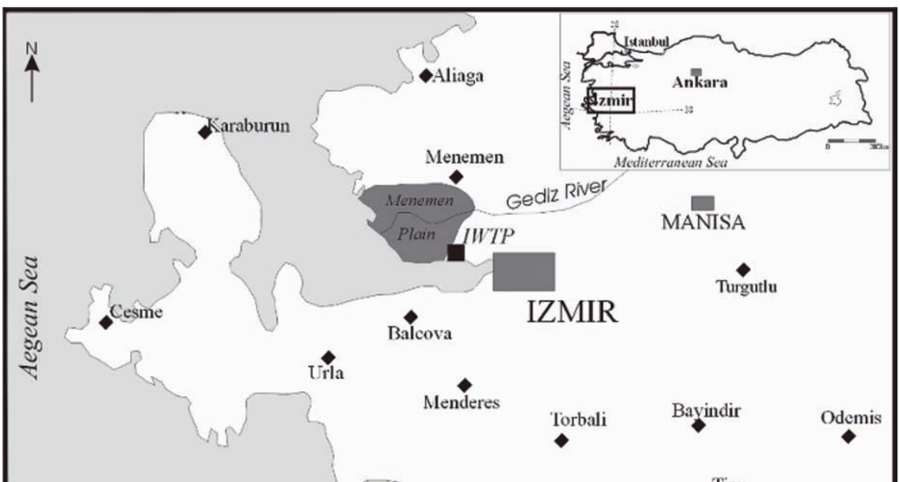

Figure 1 Location of Menemen plain and Izmir Wastewater Treatment Plant

One of the alternative water resources is the effluent of the treatment plant situated in close proximity to the Menemen plain. Although the influent of the plant generally demonstrates typical characteristics of domestic wastewater, it contains high levels of electrical conductivity and salinity, mainly attributed to the sea water intrusion from the failing pipes and improper pipe connections along the interceptor canal but also to the highly-concentrated pre-treated wastewater discharges of various industries within the city. Currently, the biologically treated effluents of the plant are discharged to the Bay of Izmir. Considering the strong demand of the farmers and the irrigation unions in the plain, this study intends to find out viable solutions to use the treatment plant effluents in the irrigation of plain. As a result, the study analyses the effluent quality with respect to the irrigation water quality standards currently effective in Turkey and offers alternative options to reduce the problems associated with high electrical conductivity and salinity.

2. Izmir Wastewater Treatment Plant

The wastewaters originating from Izmir metropolitan area are collected and transferred via an interceptor canal to two treatment plants located to the north and southwest of the city. The southwestern plant is a small unit that is constructed to serve the southwestern portions of the city. The rest of the city is served by the northern treatment plant, which is called the Izmir Wastewater Treatment Plant (IWTP) within the scope of this study. The IWTP is served by a main interceptor that runs along the shoreline and spans the entire bay. This main interceptor generally operates at atmospheric pressure under free gravity flow conditions. At the end of the interceptor, the northern treatment plant is constructed in the Menemen Plain where it is only a few kilometers away from the irrigation network serving the plain. The IWTP not only receives about 80% of all the domestic wastes of about 3.5 million population but also the pre-treated wastewaters of numerous industrial establishments situated within the city. The plant implements extended-aeration activated sludge system to biologically treat an average flow rate of 7 cubic meters per second before ultimately discharging the treated effluents to Izmir Bay.

The influent and effluent quality of IWTP are given in Table 1 and Table 2, respectively. As seen from Table 1, the influent of the plant generally demonstrates typical characteristics of domestic wastewater. However, it has been further observed that the influent water shows very high levels of electrical conductivity and salinity. These high values are mainly attributed not only to salt water intrusion due to failing pipes and improper pipe connections along gravity flow sections of the interceptor canal but also to highly-concentrated pre-treated discharges of various industries within the city.

TABLE 1 Characteristics of Izmir Wastewater Treatment Plant Influent (IZSU, 2004)

	EC µS/cm	Salinity ‰	COD mg/L	BOD mg/L	Sus. Solids mg/L	Total-P mg/L	Total-N mg/L
Apr 03	6558.97	3.73	460.92	185.19	199.01	7.91	31.31
May 03	7215.38	4.22	498.38	246.00	272.26	8.72	32.69
Jun 03	8941.07	4.99	454.81	220.00	187.53	7.74	27.95
Jul 03	9266.23	5.54	512.50	199.20	196.57	7.67	30.11
Aug 03	7881.48	4.90	519.38	192.31	208.65	8.03	31.78
Sep 03	7348.89	4.55	509.00	206.67	237.48	8.70	36.32
Oct 03	7284.62	4.50	539.96	203.70	269.28	8.95	39.69
Nov 03	7777.00	4.82	494.26	210.40	248.04	7.17	34.73
Dec 03	8740.00	4.12	395.61	208.24	225.13	7.63	32.27
Jan 04	7346.67	4.00	347.65	164.21	207.95	6.61	26.54
Feb 04	6531.67	3.50	353.42	177.39	149.45	7.47	34.34
Mar 04	-	-	453.61	242.96	194.65	8.72	39.42
Apr 04	6750.00	3.63	438.60	221.74	192.24	10.02	44.17
May 04	7816.40	4.30	504.81	220.77	242.32	9.75	40.14
Jun 04	7022.69	3.88	377.52	202.22	237.99	9.42	42.21
Jul 04	7564.23	4.20	266.88	160.00	227.46	8.62	39.68
Aug 04	8140.71	4.79	464.78	211.67	263.41	7.92	37.65
AVERAGE	**7636.63**	**4.35**	**446.59**	**204.27**	**221.14**	**8.30**	**35.35**

Relatively high concentrations of organic matter are another indicator for high strength wastewater discharges to the canal from the industrial establishments. When the effluent of IWTP is examined as shown in Table 2, one can see that the plant achieves a 90% treatment efficiency in major parameters. These levels are considered to be the optimum levels that could be attained via biological treatment with phosphorus removal. The conductivity and salinity values, however, are not changed significantly since the treatment method has no influence on these parameters. Furthermore, the comparison of IWTP effluents with discharge standards is given in Table 3 for major parameters. Accordingly, one could see that the IWTP effluents are below the discharge standards depicted in Turkish Water Pollution Control Regulation (WPCR, 1991).

Considering the possibility of using the treated wastewaters in Menemen Plain irrigation, the effluent quality is compared to the irrigation water quality criteria currently effective in Turkey (Table 4). As seen from Table 4, the effluent quality fails to satisfy the criteria with respect to the electrical conductivity value. The average value in the effluent is extremely high compared to the criteria given in Table 4 hence making the plant effluents classified as Class V waters. Such waters are considered to be harmful and unsuitable for irrigation purposes. With respect to other parameters, however, the treatment plant effluents are classified between classes I to III and are deemed to be suitable for irrigating the plain. Therefore, it would be possible to use the plant effluents in irrigation if a solution is found for the salt problem responsible for high electrical conductivity values.

TABLE 2 Characteristics of Izmir Wastewater Treatment Plant Effluent (IZSU, 2004)

	EC µS/cm	Salinity ‰	COD mg/L	BOD mg/L	Sus. Solids mg/L	Total-P mg/L	Total-N mg/L
Apr 03	6471.95	3.60	136.25	33.93	120.29	6.23	15.53
May 03	7173.85	4.12	112.17	24.75	108.78	5.43	11.24
Jun 03	8709.29	4.90	104.81	14.70	59.86	5.35	11.08
Jul 03	9043.62	5.47	107.43	11.27	58.74	5.12	9.39
Aug 03	7767.16	4.79	84.71	7.40	40.66	5.27	6.63
Sep 03	7196.30	4.40	45.21	6.85	34.68	5.82	7.82
Oct 03	7194.49	4.42	35.76	9.44	15.94	5.63	8.39
Nov 03	7659.82	4.73	40.01	10.13	20.43	4.33	6.82
Dec 03	7054.09	4.09	48.43	15.41	25.29	3.64	7.96
Jan 04	7391.54	4.09	43.94	13.61	11.70	-	10.27
Feb 04	6300.00	3.40	44.77	14.78	22.26	-	-
Mar 04	-	-	63.61	21.05	9.93	-	-
Apr 04	6472.22	3.52	43.41	29.35	6.75	-	-
May 04	7404.53	4.09	62.67	25.19	16.61	6.58	-
Jun 04	6795.38	3.75	32.42	14.33	22.92	-	-
Jul 04	7306.67	4.03	25.40	16.90	18.32	7.11	8.44
Aug 04	8055.70	4.70	43.98	18.91	25.32	5.24	7.09
AVERAGE	**7374.79**	**4.26**	**63.23**	**16.94**	**36.38**	**5.48**	**9.22**

TABLE 3 Average Quality of Effluent Discharged from IWTP

Parameter	Average Value in Effluent Apr 2003 – Aug 2004 (2-hr composite sample)	WPCR Discharge Limit (mg/L) 2-hr composite sample	24-hr composite sample
pH	7.33	6.0 - 9.0	6.0 - 9.0
COD (mg/L)	63.23	120.0	90.0
BOD_5 (mg/L)	16.94	40.0	35.0
Sus. Solids (mg/L)	36.38	40.0	25.0

TABLE 4 Irrigation Water Quality Classification (Technical Procedures Act, 1991)

Parameter	Class I (very good)	Class II (good)	Class III (moderate)	Class IV (poor)	Class V (harmful)
pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9	< 6 or > 9
Temperature	30	30	35	40	> 40
Electrical Conductivity (μS/cm)	0-250	250-750	750-2000	2000-3000	> 3000
Suspended solids (mg/L)	20	30	45	60	> 100
BOD_5 (mg/L)	0-25	25-50	50-100	100-200	> 200
NO_3^- or NH_4^+ (mg/L)	0-5	5-10	10-30	30-50	> 50
Exchangeable sodium (% Na)	< 20	20-40	40-60	60-80	> 80
Sodium adsorption ratio (SAR)	< 10	10-18	18-26	> 26	
Sodium carbonate residual (mg/L)	< 66	66-133	> 133		
Cl^- (mg/L)	0-142	142-249	249-426	426-710	> 710
$SO_4^=$ (mg/L)	0-192	192-336	336-575	575-960	> 960
B (mg/L)	0-0.5	0.5-1.12	1.12-2.0	> 2.0	-
Fecal coliform (1/100 mL)	0-2	2-20	20-100	100-1000	> 1000

3. Menemen Plain

The Menemen district is situated to the north of the city of Izmir. The Menemen Plain is formed by the alluvial deposits of the Gediz River that meets the Bay of Izmir at the western parts of the district. The plain and its vicinity are dominated by Neogene-aged deposits and volcanic rocks. The Neogene-aged sedimentary rocks are represented by claystones and clayey limestones. The volcanic rocks such as andesites and tuffs are considered to be a part of Yamanlar volcanites. The andesites and tuffs of this region cut all other units with unconformity. Finally, the Neogene-aged sedimentary and volcanic rocks are overlaid by the Quaternary alluvials, particularly observed in the Menemen plain (Somay and Filiz, 2001).

With a total length of 300 km and a total drainage area of about 17530 km^2, the Gediz River is the main water resource of the plain and its immediate vicinity. The plain covers a total area of 33000 ha of which 23000 ha is under irrigation (Beyazgul et al., 2000). Therefore, the plain is a major center for agricultural production within the immediate vicinity of the city of Izmir. The Menemen irrigation system is fed via the surface waters of Gediz River diverted by the Emiralem diversion weir. The diverted waters are then supplied to the plain via two main distribution channels and several primary and secondary channels of the network. The plain has also a drainage network to collect the return flows from irrigation.

The most important crops cultivated in the plain include cotton, vegetables, grains, maize, sesame and strawberry. Cotton covers an important percentage of the cultivated land and is considered to be the most important product of the area (Anonymous, 1991). The plain soils suffer from low yield due to salt/alkalinity problems as well as high water table problem due to insufficient drainage of agricultural return flows. In a study conducted by Delibacak et al. (2002), electrical conductivity values of Gediz River were determined to vary between 200 and 1650 μS/cm with an average of about 700 μS/cm (Table 5). Based on this average value, the Gediz River is classified Class II waters that are considered to be good for irrigation.

TABLE 5 Water quality of Gediz River (Delibacak et al., 2002)

	pH	EC (μS/cm)	Total cations (me/L)	Total anions (me/L)	SAR
Minimum	7.08	200	2.23	2.33	0.04
Maximum	8.00	1650	16.46	16.78	3.30
Average	7.62	696	6.98	7.12	1.08

In addition to the diverted waters of Gediz, many farmers dig wells in their properties and use groundwater to irrigate their fields when the amount of surface water supplied to them is insufficient. In this regard, there are numerous shallow and deep wells drilled in the alluvial surfacial aquifer in the plain. While the depths of shallow wells range between 5-20 m, several deep well are dug at depths more than 100 m. The electrical conductivity values observed in these wells are analyzed and correlated with the agricultural fields that receive their waters as shown in Table 6. In essence, about 50% of the agricultural land studied in the plain contains groundwater that has Class 4 and 5 waters with respect to electrical conductivity making the plain vulnerable to salinity problems.

TABLE 6 The electrical conductivity values in the groundwater (Anonymous, 1991)

Electrical Conductivity	Area (ha)	Area (%)
0-1000	1678	25
1000-2000	1690	26
2000-3000	2218	34
3000-5000	525	8
> 5000	442	7
Total	6553	100

4. Vulnerability to Pollution

In order to evaluate the vulnerability of Menemen Plain surfacial aquifer to contamination from surface pollution sources; the DRASTIC model developed by the U.S. Environmental Protection Agency (Aller and others, 1987) is used. The method is based on the idea of using several hydrogeological parameters (i.e., depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity) in defining the conditions of the underlying aquifer and extracting the associated susceptibility to pollution. The linear combination of the ratings and the weighing factors of these parameters provide the numerical value of the DRASTIC index, which is then used to evaluate the vulnerability of the aquifer based on six different categories. These categories classify the aquifer based on very low, low, moderate, high, very high and extremely high vulnerability to contamination (Table 7).

TABLE 7 DRASTIC Index Classification

DRASTIC Index Range	Degree of Vulnerability
< 79	Low
80 – 119	Medium
120 – 159	High
160 – 184	Very high
> 185	Extremely high

TABLE 8 DRASTIC Index values for the wells in Menemen Plain.

Location of the well	DRASTIC Index	Location of the well	DRASTIC Index
Seyrek	130	Musabey	130
Gunerli	130	Well no. 2825	125
Kesikkoy	130	Well no. 1913	125
Suzbeyli	150	Well no. 35/3183	130
Tuzcullu	140		

In Menemen plain, the analysis is performed at 9 sampling points (Seyrek, Guneyli, Kesikkoy, Suzbeyli, Tuzcullu, Musabey, Well 2825, Well 19013 and Well 35/3183) where sufficient data is available with respect to the DRASTIC parameters mentioned above. The results revealed a relatively narrow range (i.e., 125 – 150) of DRASTIC index values, which indicated that the groundwater resources of Menemen plain have high hydrogeological vulnerability to pollution (Table 8). Therefore, the groundwater potential of the plain must be carefully protected if it is to be used as an alternative source for irrigating the plain.

5. Alternative Formulations for the Reuse of Izmir Wastewater Treatment Plant Effluent in Menemen Plain Irrigation

It is known that waters with high salt content tend to create salinity and alkalinity problems in soils and hence must be avoided as an irrigation water resource. With its high electrical conductivity and salinity values, the IWTP effluents are hence not suitable for irrigating the plain. Considering the high conductivity values (i.e., an average of about 7000 μS/cm) in the effluent, the plant effluent can not be used directly in irrigating the plain. On the other hand, the farmers and irrigation unions are in desperate need to use the treated effluents as an extra resource in addition to the Gediz river waters. Originating from this dilemma, a two step solution is proposed. Accordingly as a first step, it is proposed that the treated waters are diluted with other water resources to reduce the electrical conductivity values. It is important to note that this dilution is to be done with waters that contain conductivity values below 3000 μS/cm. Alternatives include the original irrigation water supplied from the Gediz River, the waters to be supplied from groundwater or the treated effluents of the nearby Ataturk Organized Industrial Zone. Careful mass balance computations must be performed to compute the final values of conductivity and salt contents after dilution. Even if groundwater is used for this purpose, not only the amount of water available for farmers will increase, but also it will be possible to direct groundwater to other uses like industrial water supply as a result of the reduction of irrigation water consumption owing to the use of treated wastewater. Hence, it seems more logical to mix the IWTP effluents with Gediz River waters particularly for irrigating cotton fields as the tolerance of this crop is much higher than other plants cultivated in the plain.

While the first step is only an attempt to temporarily solve the problem, the permanent solution would involve not only the minimization of sea water seepage to the interceptor canal but also the prevention of the discharge of high strength wastewaters of the industries to the canal. Rehabilitation works must be implemented along the interceptor such that the pipes and pipe connections are improved against sea water seepage. Once these improvements are done, the sea water infiltration will be minimized and the high electrical conductivity values will be reduced to normal levels. Hence, the treated waters would then be easily used in irrigation without the need for dilution.

6. Conclusions

This study is intended to investigate the possibility and technical viability of using the effluents of northern treatment plant in Menemen plain irrigation. The research verified the fact that the influent of the plant generally demonstrates typical characteristics of domestic wastewater with the exception of high electrical conductivity and salinity values attributed due to sea water intrusion along the interceptor channel and pre-treated discharges of various industries. Based on the current quality criteria, the plant effluent is not suitable for irrigation and requires that certain measures needs to be taken to improve its quality. One such measure is to dilute the treated effluents with other water resources that are low in electrical conductivity. The long term solution to the problem, however, will require the need for the rehabilitation of the interceptor channel to minimize the sea water infiltration via various engineering techniques.

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ASSESSMENT OF RAINWATER ROOF HARVESTING SYSTEMS FOR HOUSEHOLD WATER SUPPLY IN JORDAN

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Abstract. The largest environmental challenge that Jordan faces today is water scarcity. This scarcity attributed to climatic conditions, such as aridity and abundance of high solar radiation, and population pressure. Current use already exceeds renewable supply. Many methods have been suggested to increase the sources of water supply, one alternative source is rainwater harvesting. This paper aims at evaluating the importance of rainwater roof harvesting systems for domestic supply in Jordan. General domestic water storage patterns and design considerations of roof water harvesting systems have been addressed. Moreover, it estimates the maximum amount of rainwater, which may be collected in cisterns using roof catchment systems. Finally, recommendations to improve the quality and quantity of harvested rainwater have been provided.

Keywords: Jordan; household; rainwater; water harvesting; water supply.

1. Introduction

Jordan is located 80 kilometers east of the eastern coast of the Mediterranean Sea. It is located between 29° 11'N and 33° 22'N, and between 34° 19' E and 39° 18'E. Jordan has an area of 89,213 sq km, land area is 88,884 sq km and the area covered with water is equal to 329 sq km (Salameh and Bannayan, 1993).

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Jordan has suffered deficits in water resources since 1960s; the country is classified as water scarce compared with countries in the region. The scarcity of water resources in Jordan seems to be dictated by climatic conditions, such as aridity and abundance of high solar radiation, and by population pressure which sprang at a location distant from water resources (Salameh and Bannayan, 1993). The increasing pressure on the available resources represent the challenge for scientists, engineers and policy makers because the entire development of the country in the different fields depend on the availability of this vital resource.

Search for a new water resource starts with an effort to decrease the present amount of water lost in the distribution system. Equally important is the collection of rainwater in economically feasible water wells (cisterns). It must be stressed that rainwater is the only source, which is easy to obtain individually and with minimum cost. The only thing, which a person needs, is the roof of the house to collect the rainwater and a place to store it. Since ancient times, farmers and herders in the Mediterranean have, under widely varying ecological conditions, attempted to 'harvest' water to secure or increase agriculture production. A wide range of indigenous techniques can be found in areas between 100 and 1000 mm annual precipitation and with population densities varying from 10-300 persons/km^2. Rainwater catchment systems have been used in Jordan since 850 B.C., rainwater have been used for both domestic and irrigation purposes, people continue to collect rainwater in spite of availability of water distribution systems due to the shortage of water (Prinz, 1995).

The rainy season in Jordan extends from October to April, with the peak of precipitation taking place during January and February. The average annual rainfall under normal climatic conditions is 300 mm. The flood water is mostly lost by evaporation, it is estimated that volume of water lost in this manner exceeds all the utilized sources of water in the country, harvesting this water should be a priority. The amount of water, which may be collected from a roof area of 125 m^2 in the rainy season, is about 35 m^3 (Salameh and Bannayan, 1993).

Collecting the rain that falls on a building to be used started to attract attention of people and government; roof rainwater harvesting is like any engineering system has its own advantages and disadvantages. The main advantages are: sources of energy are not needed to operate the system, quality of rain water can be used as a primary source for specific uses and so reduce the water bill, does not come into contact with soil and rocks where it dissolves salts and minerals it is soft and can significantly reduce the quantity of detergents and soaps needed for cleaning, very good for areas that are not served with water, relatively limited technical knowledge is required and it is easily understood, it uses local construction materials and labor, the owner user can easily maintain the system, decrease local erosion and flooding caused by runoff from impervious cover such as pavement and roofs, the technology is usually found to be economically, socially and environmentally acceptable.

The main disadvantages are: the quantity of rain water available depends or rainfall high initial cost of building the permanent storage facilities, the primary expense is the storage tank, mineral-free water is tactless and could cause nutritional deficiencies people prefer to drink water rich in minerals. The present study emphasizes the importance of rainwater roof catchment systems for domestic water supply in Jordan. It first reviews the general domestic water storage patterns and harvesting with roof catchment systems. Second, the study emphasis the importance of rainwater roof harvesting systems for domestic supply in Jordan and to establish the viability of the Rain Water Harvesting (RWH) as a sustainable method of conserving water. Third, the study estimates the maximum amount of rainwater which may be collected in cisterns using roof catchment systems in Jordan governorates. Finally, the study provides some suggestions and recommendations regarding the improvement of both quality and quantity of rainwater collected. In this study, a questionnaire was designed to collect data and information about roof water harvesting practices in Jordan. The questionnaire includes general questions about the study area besides questions related to rainwater roof catchment system such as the method of collecting rainwater, design and construction of the cistern, rainwater use water quality, etc. A total 60 questionnaire and samples of 30 homes were included in this study, the survey took four months to complete. The completed questionnaire data were entered to the computer for further analysis. The major results of the survey are presented in the following sections.

2. Rainwater Roof Catchment System Components

There is a considerable range in complexity of domestic rainwater harvesting systems. Whether you are planning to construct a large system or small system for rainwater harvesting, the system must include three basic components: roofs, gutters and storage tank (Texas water development board, 2005). These components are described below.

2.1. ROOFS

The collection area in most cases is the roof of a house or a building. Smoother, cleaner and more impervious roofing materials are preferred; they contribute to better water quality and greater quantity. Tiled roofs, or roofs sheeted with corrugated mild steel etc., are preferable, since they are the easiest to use and give the cleanest water (Alpaslam et al., 1992).

In Jordan, two types of roofing material are used; these are cement, tile, and asphalt. Cement and tiled roofs are the most common roofs due to its durability, relatively low price, and provide good quality water, Composite asphalt, asbestos, and some painted roofs are recommended only for non-potable water use because they could leach toxic materials in to rain water as it touches the roof surface. Regardless of roofing material, many designers assume up to a 20% loss on annual rainfall, these losses are due to: roofing material texture, evaporation, losses occur in gutters and in storage, and inefficiencies in collection process.

2.2. GUTTERS, DOWNSPOUTS AND ROOF WASHERS

Gutters and downspouts catch the rain from the roof catchments surface and transport it to the cistern; they must be properly sized, sloped and installed in order to maximize the quantity of harvested water. The most common materials of gutters are seamless aluminum, Galvanized steel, cooper, stainless steel are also used for gutters and downspouts but they are more expense.

The gutters and down pipes are usually installed in the wall of the building, and sometimes the down pipes are fitted inside the wall during construction. The size of the gutters depend upon the area of the roof and the rainfall amount, the size of the gutters used ranges between 20-50 cm diameter (Alpaslam et al., 1992).

The purpose of the roof washers is to collect and disposal of the first flush of water from a roof, especially where the collected rain water is to be used for human consumption. First-flush devices ensure a certain degree of water quality in harvested rainwater. The first five gallons of runoff from a gutter, roof or other surface is likely to contain various impurities such as bird droppings and dust. A first-flush device prevents this initial flow from draining into the storage tank. Many first-flush devices are simply and cleverly designed. Such devices include tipping buckets that dump when water reaches a certain level (Abu Sharekh, 2002).

2.3. STORAGE TANK (CISTERNS)

Storage tank is used to store the water that is collected form the rooftops. The storage tank represents the major cost in the system. There are unlimited number of options for the construction of these tanks with respect to the shape (cylindrical, rectangular and square), the size, and the material of construction (brickwork, stonework, cement bricks, Ferro cement, plain cement concrete and reinforced cement concrete) (Alpaslam et al., 1992).

Concrete tanks are the most common used tanks in Jordan; they can be built above or below ground. They're usually made on site and are durable and long lasting. However, they can sometimes crack - especially when they are below ground in clay soil. They're good for preventing algal growth (light can't penetrate) and they keep water cool (Abu Sharekh, 2002).

The cistern can be either above or below the ground. Above ground tanks are easy to detect cracks and leaks, water can be extracted via gravity and/or pumps, they can also be raised off ground to increase water pressure, they are easy to drain for cleaning, and usually cost less than below ground tanks[3]. But they take up space, they are subjected to weather conditions, and require anchoring to the ground for when the tank has lees water. Below ground tanks can save space, but they are more difficult to extract water from - usually need a pump, it is hard to detect leaks or problems, they are difficult to drain for cleaning, there is a risk of contamination from groundwater or floodwaters, it can be damaged by tree roots, if access point is left uncovered, there's a risk of children, adults and animals drowning or contaminating the water and usually have a large excavation costs (Gould, 1993).

3. Advantages and Disadvantages of Roof Rainwater Harvesting

Collecting the rain that falls on a building for later use started to attract attention of people and government; roof rainwater harvesting is like any engineering system has its own advantages and disadvantages.

The main advantages are:

- Sources of energy are not needed to operate the system.
- Quality of rain water can be used as a primary source for specific uses and so reduce the water bill.
- Does not come into contact with soil and rocks where it dissolves salts and minerals it is soft and can significantly reduce the quantity of detergents and soaps needed for cleaning.
- Very good for areas that are not served with water.
- Relatively limited technical knowledge is required and it is easily understood.
- It uses local construction materials and labor.
- The owner user can easily maintain the system.

- Decrease local erosion and flooding caused by runoff from impervious cover such as pavement and roofs.
- The technology is usually found to be economically, socially and environmentally acceptable.

The main disadvantages are:

- The high initial cost of building the permanent storage facilities, the primary expense is the storage tank.
- The quantity of rain water available depend or rainfall, for long periods of drought it is necessary to store excessively large volume of water.
- The mineral-free water is tactless and could cause nutritional deficiencies people prefer to drink water rich in minerals.

4. (RRWH) Prospects for Jordan Governorates

Rainfall harvesting from rural/urban catchments has not received large attention in Jordan. In the absence of runoff sewer lines in Jordanian rural areas, rainfall harvesting from roads, parking lots and rooftops can increase water supply for various domestic uses and help combating the chronic water shortages in the country. Catchment of rainfall drainage from a building roof with tank storage is the commonest practice. In this project, water harvesting yields are calculated for residential roofs and the amounts of rainwater that can collected from private single households roofs only were calculated for the twelve governorates in the kingdom. Data for 2004 were the most recent data available at the time of the preparation of this analysis (Department of Statistics, 2004). Annual rainfall- runoff water harvest yields Y, are calculated using the following:

$$Y = (R\ A\ C/1000) \qquad [m^3/yr] \qquad (1)$$

Where: R = average annual rainfall, mm; A = roof or drainage area, m^2; C = runoff coefficient (we will use $C = 0.8$) (Gould, 1993).

Table 1 summarizes the estimated gross yield for the twelve governorates.

In towns and villages where domestic usage is generally lower, RRWH from roofs can be expected to provide an even higher percentage of the daily demand. New homes in Jordan are now required to have water collection reservoirs, as municipalities around the country were issued, a government directive not to accept penalties in place of wells. The decision was made in line with the Water and Irrigation Ministry policy of maximizing citizen use of water resources and encouraging rainwater harvesting during the winter season.

TABLE 1 Annual potential yield of water harvesting for Jordan governorates

Governorate	Estimated yield (m^3)	Governorate	Estimated yield (m^3)
Amman	5,711,996	Jarash	834,614
Balqa	3,139,719	Ajlune	1,210,206
Zarqa	946,685	Karak	1,270,518
Madaba	683,709	Tafiela	392,507
Irbid	6,025,031	Maan	71,667
Mafraq	657,903	Aqaba	37,097

A survey for 60 homes in Amman and Irbid Governorates was conducted to assess the status of rainwater harvesting and to evaluate rainwater harvesting practices. The survey revealed that the per capita consumption was 88 l/day. This estimation based on eight quarters bells collected from these homes. The most important results from the questionnaire are:

- The roofing material used is concrete. In some of the households theconcrete surface is covered either by tiles or asphalt.
- Gutters and downspouts are made from plastic.
- Only 60% of the houses use the first flush technique
- Only 30% of the houses use some treatment practices (either boiling or filtering) before drinking.
- All cisterns were made from reinforced concrete and all of them are located under the ground.
- Most of the cisterns were subjected to maintenance every year at the end of the dry season.
- The harvested water is mainly used for irrigation or cleaning purposes, some houses only rely on the harvested water as a source for drinking and cooking (see Table 2 for the uses of harvested water in Amman and Irbid Cities).

TABLE 2 Uses of harvested roof rainwater in Amman and Irbid Cities

City	Drinking and Cooking only (%)	Irrigation and Indoor uses only (%)	Both (%)
Amman	16.7	53.3	30
Irbid	40	26.6	33.4

5. Water Quality Consideration

The quality of rain water depend on where the system is located, it can be affected by espousing to air pollution, automobile emissions. The stored rainwater will not always meet WHO standards (WHO, 1993). Rainwater is usually free from physical contaminants such as pesticides, lead, and arsenic, color and suspended materials and it is low in salt and hardness problems. Regular maintenance assists in gaining good quality water from rainwater tanks .The storage tank should be cleaned periodically, inner walls and floor should be scrubbed, and then clean the cistern using chlorine, followed by thorough rinsing, cracks should be patched with a non-toxic material, access to the cistern should be taken into consideration while designing the tank (WHO, 1993).

A study was conducted to evaluate the quality of the harvested rainwater from the roofs of the houses, the study for the cisterns rainwater quality carried out in the Amman (Tariq area) and Irbid city. These two areas were chosen because rainwater harvesting systems are widely used in them, and there climatic conditions are similar to each other. The study examined physical, chemical and biological water quality parameters. Samples were collected, tested and analyzed during the study.

The chemical analysis included the determination of total chlorine concentration. The analysis also included measurement of PH, electric conductance, total dissolved solids, O_2 saturation percent and total hardness. Table 3 presents the results of chemical and physical analysis .from the results below we can notice that none of the chemical constituents exceeded WHO standards with the exception of some high and low values of some parameters. This means that, chemically, the cisterns water is of high quality and very suitable for drinking for domestic purposes.

TABLE 3 Results of chemical and biological analysis of cistern water samples

Constituents	WHO standards (mg/l)	Min. (mg/l)	Max. (mg/l)	Average of 60 (mg/l)
Temperature	-	16.3	19.7	18.6
pH	6.5-9.2	7.1	8.6	7.4
O_2 percent of saturation	-	50%	77%	61.5%
TDS	200-500	76.38	681.1	270.2
EC(μs/cm)	<250	114	1017	402.6
Total Hardness	500	50	270	140.3
Total Chlorine	-	0.0	0.22	0.055
Total coliform counts in 100 ml samples	0	11	56	33

In this study, biological contamination tests were limited to the investigation of the presence of total coliforms. Samples from 60 rainwater cisterns were tested. The results indicated that collected water do not meet WHO standards. The collected water should be chlorinated at least once every rainy season and preferably after the cistern gets full of rainwater. The sources of microbiological contaminations are the human and animal waste present in the cistern catchment area. Cleaning the catchment area before the rainy season starts is a must and people should be aware of that all the time.

6. Conclusion

Jordan has a serious and worsening water supply problem. It should then be heartening to realize that at least some relief can be had through winter rains which can be collected and stored in man-made cisterns. Clearly rainwater (rainfall which is directly collected as the roof runoff from buildings) has a major role to play in substituting and/or supplementing urban water supply from centralised water supply facilities. Generally, it is considered that roof rainwater harvesting (RRWH) waters would be used for secondary purposes, augmenting the basic supply in urban areas having approved water distribution systems. In some remote areas with scarce rainfall, RRWH may constitute a primary water supply. A great potential for exploitation of rainwater harvesting from houses roofs is possible in Jordan. The use of rain water to supplement the potable water supply in Jordan has been demonstrated to be practical and effective where traditional ground water and/or surface water are limited. Even if it cannot change the total supply, it can make a significant difference for many poorly served localities. Cultural habits, pattern and standard of living, methods of withdrawal, cost and quality of water will greatly influence the use of rainwater for domestic purposes. Rainwater is one of the purest sources of water available. Its quality almost always exceeds that of ground or surface water. It does not come into contact with soil or rocks where it can dissolve minerals and salts nor does it come into contact with many of the pollutants that are often discharged into local surface waters or contaminate ground water supplies. However, rainwater quality is influenced by where it falls. There are a number of different rainwater harvesting systems available, but a typical example would be rain collected from the roof traveling via a drainpipe into a storage tank (usually underground) once the leaves and debris have been filtered out. Considering the prevalence and importance of cisterns it is surprising that they have been given so scant attention. The reason may be that the individual cisterns are so small. What make them valuable are however the fact that when they combined they give a tremendous capacity. There is a need to improve understanding of the social impact, potential and performance of partial RWH as practiced by families in small houses, assessing its cost and benefits and to improve the domestic roof rainwater harvesting (DRWH) technology itself. Rainwater harvesting can not only provide a source of water to increase water supplies but also involve the public in water management, making water management everybody's business. It will also reduce the current demand on government Institutions to meet water needs, reduce the need for government subsidies, and help everyone to internalize the full costs of their water requirements, thus encouraging the public to be more conserving in its water demand.

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WASTEWATER REUSE FOR IRRIGATION ON THE DESERT SANDY SOIL OF EGYPT: LONG-TERM EFFECT

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Abstract. In Egypt, the reuse of sewage water on the sandy soil of El-Gabal El-Asfar Farm took place since 1923. The present work discusses the physical and chemical characteristic of this water. Different soil samples that were irrigated by sewage for different increasing periods were collected to investigate the changes in the soil texture as well as accumulation of heavy metals by the soils according to the period of irrigation (7, 12, 23, 40, 50 and 75 years). The overall results revealed that the longer period of irrigation demonstrated higher level of metal accumulation in the soil. The progressive increase of metals in the soil represents serious risk to the cultivated plant (as a food cycle). It is; therefore; recommended to decrease the level of heavy metals in sewage water via further simple wastewater treatment. For this purpose, a laboratory attempts were carried out to decrease the level of metals in the sewage water. Lime, as coagulant, and/or the dried leaves of Water Hyacinth plant were examined. Remarkable elimination of metals was demonstrated. It was also recommended to use the given sewage water for cultivating the woody or Lumber trees (for high economic revenue) to reduce any expected metal hazard in the food chain.

Keywords: accumulation of metals; environmental problems; impact of sewage irrigation; sandy soil; sewage farm; wastewater reuse.

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1. Introduction

The discharges of sewage and drainage water to the waterways represents the major sources of pollution to the environment and the aquatic biota (Foerstner and Wittmann, 1983; Freeman, 1988). Such discharge deprives agricultural land of two scarce materials, namely water, plant nutrients and sandy soil fertility (German and Svensson, 2001; El-Gamal and Abdel-Shafy, 1990). In Egypt, sewage application takes place on sandy soil of El-Gabal El-Asfar desert area since 1923. This area has no means of water irrigation and suffers from an inherent lack of organic matter as well as micro-and macronutrient elements (Mansour, 1996; El-Gamal and Abdel-Shafy, 1991). The most serious threat is the accumulation of heavy metals in the irrigated soil (Abdel-Shafy et al, 2003). The present investigation was carried out to study the effect of sewage irrigation for different periods, namely 7, 12, 23 and 40 years on the desert sandy soil in terms of texture and heavy metals accumulation. The arising questions, therefore, are: What is the impact of using sewage water for irrigation on the sandy soil at long-term bases with respect to soil texture and accumulation of heavy metals? How can we optimize the reuse of sewage for irrigation without risk.

2. Materials and Methods

The subject of the present investigation is El-Gabal El-Asfar sewage farm. The Farm locates in El-Qalyubilya Governorate; at the eastern desert 25 km northeast Cairo. The area is a desert sandy soil. Primary treated sewage water was used for irrigating this Farm. The present investigation was carried out during three successive seasons for a period of three years on the sandy soil which was irrigated by sewage water for different periods, namely 7, 12, 23 and 40 years. Meanwhile, the effect of irrigation with fresh water for a period of 50 years within the same sandy soil area was studied for correlation purpose.

An extensive study program was designed to collect water and soil samples for the determination of the physical, chemical characteristics according to APHA, 1995. The soil samples were collected at depth (0-15), (15-30), (30-45) and (45-60) cm successively. Soil texture was conducted according to Piper, 1966 and Jackson, 1967. Level of heavy metals was carried out according to Lindsay and Norvell, 1978. A Jar-Test Experiments as described by Culp and Culp (1974) were conducted to investigate the effect of both lime and the water hyacinths plant on the elimination of metals in the sewage water.

3. Results and Discussion

3.1. CHARACTERISTICS OF IRRIGATION WATER AT GABAL ASFAR FARM

Results obtained showed that pH ranged from 6.85 to 7.75. Electric conductivity ranged from 0.95 to1.11 mmoh/cm at 25 ^{O}C. The mean values of Mg, Na and K were 67, 322 and 63 mg/l respectively. The mean values of HCO_3^-, Cl^-, $SO_4^{--}$and NO_3^- were 208, 125, 354 and 14 mg/l respectively. Meanwhile, the studied parameters exhibited slightly higher levels in the summer than during winter seasons, with the exception of EC. It is worth noting that Na^+ and SO_4^{--} were the highest cation and anion, respectively. However, there was no great variation between the values in both summer and winter. Level of heavy metals is given in Table (1). The results indicated that Fe exhibited the highest level, while Cd was the lowest in the sewage water. Meanwhile, slight variation can be noticed during the successive months of the year. The results showed also that the level of metals in summer was slightly higher than in winter. This may be due to increasing the rate of evaporation of this primary treated sewage during the hot summer months. Level of metals in sewage water during the summer can be arranged according to the following decreasing order:

Fe > Al > Ni > As > Mn > Zn > Cr > Pb > Se > Cu > Co > Cd

It is worth noticing that only Cu, Zn, Al and Co (Table 1) is within the permissible limit according to WHO, 1978 and Egyptian regulation, 1994. The other metals are over the permissible limits. It is recommended therefore, that such water should be treated before using for irrigation to reduce the levels of metal down to the permissible limits. It is well known that metals can be accumulated in the soil via irrigation with contaminated water (Abdel-Shafy and Aly, 2002). Meanwhile, metals can find their way to plants through the contaminated soil and finally to the food cycle (El-Gamal and Abdel-Shafy, 1990; Abdel-Sabour, Abdel-Shafy and Mosalem, 2001).

For correlation purpose, the physical and chemical characteristics of the fresh canal water were studied. Results obtained showed that pH ranged from 7.09 to 7.62. Electric conductivity ranged from 0.35 to 0.52 mmoh/cm at 25 ^{O}C. The mean values of Mg, Na and K were 25.5, 219 and 14 mg/l respectively. The mean values of HCO_3^-, Cl^-, $SO_4^{--}$and NO_3^- were 262, 104, 87 and 2.9 mg/l respectively. Again, the studied parameters exhibited slightly higher levels in the summer than during winter seasons, with the exception of EC and NO_3^-. Similarly, no great variation was detected between the values in both summer and winter seasons. Level of heavy metals in this water is given in Table (2).

TABLE 1 Level of heavy metals in the sewage water that are used for irrigation at El-Gabal Al-Asfar Farm during the winter and summer seasons.

Season	N	Parameter	Content of Elements (mg/l)											
			Fe	Cu	Mn	Zn	Al	Se	Pb	Cd	Co	Cr	Ni	As
Winter	9	Max.	9.343	0.173	0.536	0.321	0.595	0.256	0.193	0.075	0.072	0.374	1.037	0.233
		Min.	0.758	0.010	0.102	0.182	0.184	0.011	0.089	0.002	0.021	0.045	0.462	0.121
		M.V.	3.642	0.077	0.244	0.238	0.261	0.070	0.149	0.014	0.044	0.130	0.737	0.163
		SE±	1.07	0.021	0.052	0.079	0.045	0.026	0.148	0.054	0.007	0.041	0.063	0.019
Summer	8	Max.	9.871	0.280	0.454	0.375	2.523	0.176	0.271	0.066	0.151	0.745	1.342	0.822
		Min.	2.222	0.025	0.089	0.146	0.362	0.032	0.125	0.003	0.043	0.025	0.671	0.137
		M.V.	5.208	0.087	0.255	0.253	1.689	0.146	0.180	0.024	0.084	0.248	0.994	0.315
		SE±	0.929	0.028	0.039	0.028	0.248	0.062	0.093	0.081	0.017	0.095	0.082	0.201
T.A.V.			4.425	0.082	0.249	0.245	0.975	0.108	0.165	0.019	0.064	0.189	0.865	0.239
Egyptian Law 1994			1.00	1.00	0.05	1.00	3.00	0.02	0.050	0.05	0.05	0.10	0.10	0.10
WHO			0.10 1.00	0.05 1.50	0.05 0.50	5.00 15.00	3.00 5.00	0.01 0.02	* 0.10	* 0.01	0.01 0.18	0.10 0.10	* *	0.05 0.05

Max. : Maximum
Min. : Minimum
N : Number of Samples
M.V. : Mean Value
SE± : Standard Error

TABLE 2 Level of heavy metals in the Canal water that are used for irrigation during the winter and summer seasons

Season	N	Parameter	Content of Elements (mg/l)											
			Fe	Cu	Mn	Zn	Al	Se	Pb	Cd	Co	Cr	Ni	As
Winter	9	Max.	2.462	0.093	0.372	0.213	0.384	0.046	0.171	0.031	0.082	0.025	0.347	0.148
		Min.	0.654	0.006	0.050	0.053	0.119	0.027	0.028	0.004	0.001	0.003	0.186	0.013
		M.V.	1.439	0.048	0.153	0.148	0.228	0.039	0.096	0.011	0.019	0.010	0.240	0.061
		SE±	0.218	0.01	0.092	0.055	0.089	0.004	0.045	0.006	0.01	0.002	0.019	0.016
Summer	8	Max.	2.419	0.077	0.373	0.324	0.985	0.056	0.191	0.022	0.098	0.084	0.871	0.161
		Min.	0.594	0.022	0.056	0.157	0.113	0.027	0.032	0.015	0.006	0.002	0.182	0.015
		M.V.	1.828	0.051	0.230	0.199	0.412	0.043	0.147	0.018	0.021	0.014	0.437	0.081
		SE±	0.349	0.007	0.153	0.157	0.094	0.004	0.023	0.004	0.012	0.01	0.096	0.019
T.A.V.			1.622	0.049	0.189	0.172	0.314	0.041	0.120	0.014	0.020	0.012	0.333	0.071
Egyptian Law 1994			1.00	1.00	0.05	1.00	3.00	0.02	0.050	0.05	0.05	0.10	0.10	0.10
WHO			0.10 1.00	0.05 1.50	0.05 0.50	5.00 15.00	3.00 5.00	0.01 0.02	* 0.10	* 0.01	0.01 0.18	0.10 0.10	* *	0.05 0.05

Max. : Maximum

Min. : Minimum

N : Number of Samples

M.V. : Mean Value

SE± : Standard Error

Results exhibited much lower values in the physical, anions, cations and heavy metals as well in correlation to the wastewater.

3.2. EFFECT OF SEWAGE IRRIGATION ON CHARACTERISTICS OF FARM SOIL

Table (3) represents the particle size distribution, calcium carbonate, organic matter, pH and electrical conductivity (EC) of the soils at different periods of irrigation with sewage water and/or with canal water. The data shows that there is a positive change in soil texture depending on the period of sewage irrigation as well as the soil depth. Such changes are more pronounced in the surface layer (0-15 cm) than subsurface layers. For the clay content at the surface layer, it increased from 0.04% for the non-cultivated soil to 12.92%, 16.81%, 19.05% and 20.50% for the soil irrigated with sewage water for periods of 7, 12, 23, and 40 years, respectively. Consequently, the sandy soil texture improved to loamy sand after 7 years and to sandy clay loamy after 40 years of irrigation with sewage water. Such improvement in soil texture is mainly attributed to the penetration and sedimentation of the suspended matters that associated with the sewage water between the sand particles of the soil. This founding is in consistence with other investigators (Hall, L'Hermite and Newman, 1992; Abdel-Shafy and Troeger, 1998).

Meanwhile, there is a gradual decrease in calcium carbonate content as well as the pH in the surface layer of the studied soil. The longer period of irrigation the more decreasing effect occurred. The $CaCO_3$ content decreased from 1.21% in the surface layer of the non-cultivated soil to 1.12%, 0.84%, 0.71% and 0.66% for soils irrigated with sewage water for 7, 12, 23, and 40 years, respectively (Table 3). Such decrease can be attributed to the washing out of $CaCO_3$ from the sandy soil by sewage irrigation. Therefore, such decrease was more pronounced in the topsoil more than the sub-soil layers. On the other hand, slight decrease in the calcium carbonate concentration was observed for the soil related to canal water. It is important to notice that the later soil contained the highest level of carbonates than the other soils that were irrigated by sewage. This result is consistence with other workers (El-Gamal and Abdel-Shafy 1991; Abdel-Shafy and Troeger, 1998).

On the contrary, electric conductivity (E.C.) and the organic matter content of the studied soil were increased in the surface layer according to the period of sewage irrigation Table (3). The organic matters in the top soil layer (0-15 cm) increased from 0.05% for non-cultivated soil to 3.25%, 4.38%, 4.93% and 5.63% for the soils irrigated with sewage water for 7, 12, 23, and 40 years, respectively. This increase is mainly rendered to the fact that sewage water contained appreciable amounts of suspended matter that caused soil enrichment.

TABLE 3 Particle size distribution (Texture) for different types of soil at variable depths, as well as, the pH, electrical conductivity (EC), organic matter (O.M.) and $CaCO_3$ in each soil at El-Gabal El-Asfar sewage Farm

Period of Irrigation Years	Type of Water	Soil depth (Cm)	Texture				Soil Texture	$CaCO_3$ %	O.M. %	EC (ds/m)	PH
			Coarse Sand %	Fine Sand %	Silt %	Clay %					
0	Non-Cult.	0-15	77.80	21.96	0.20	0.04	Sandy	1.30	0.05	0.75	7.81
		15-30	73.83	26.10	0.04	0.03	Sandy	1.20	0.03	0.51	7.88
		30-45	67.65	32.28	0.03	0.04	Sandy	1.14	0.02	0.36	7.84
		45-60	77.30	22.64	0.04	0.02	Sandy	1.18	0.02	0.30	7.81
Mean			74.15	25.74	0.07	0.03	Sandy	1.21	0.03	0.48	7.83
7	S.W.	0-15	63.82	21.62	1.64	12.92	L.S.	0.82	3.25	1.12	6.30
		15-30	62.34	25.65	2.72	9.29	L.S.	1.13	1.95	0.73	6.33
		30-45	79.64	13.65	2.52	4.19	Sandy	1.20	0.83	0.55	6.42
		45-60	82.60	10.84	2.98	3.58	Sandy	1.35	0.25	0.48	6.85
Mean			72.10	17.95	2.46	7.49	Sandy	1.12	1.57	0.72	6.47
12	S.W.	0-15	63.88	16.98	2.33	16.81	S.L.	0.95	4.38	1.70	6.10
		15-30	68.52	16.90	2.01	12.57	S.L.	1.36	3.02	1.38	6.20
		30-45	75.80	10.28	1.95	11.97	S.L.	0.55	1.22	0.86	6.00
		45-60	62.07	27.22	0.85	9.86	Sandy	0.51	0.42	0.60	6.20
Mean			67.57	17.84	1.79	12.80	Sandy	0.84	2.26	1.13	6.12
23	S.W.	0-15	39.55	37.65	3.75	19.05	S.L.	0.68	4.93	1.80	6.00
		15-30	71.00	14.40	1.70	12.90	L.S.	1.19	1.62	1.31	6.10
		30-45	60.60	21.40	4.00	14.00	L.S.	0.50	0.38	0.80	6.15
		45-60	82.50	7.65	3.00	6.85	Sandy	0.47	0.25	0.84	6.11
Mean			63.41	20.28	3.11	13.20	Sandy	0.71	1.80	1.19	6.09
40	S.W.	0-15	56.40	5.50	17.60	20.50	S.C.L.	1.64	5.63	2.60	6.08
		15-30	55.00	7.80	16.80	20.40	S.C.L.	0.94	2.43	1.21	6.00
		30-45	61.60	6.20	14.50	17.70	S.L.	0.65	0.80	0.63	6.00
		45-60	88.30	2.30	1.80	7.60	Sandy	0.59	0.18	0.80	6.30
Mean			65.33	5.45	12.68	16.55	Sandy	0.96	2.26	1.31	6.11
50	Canal	0-15	68.50	14.73	3.60	13.17	L.S.	3.72	0.43	1.01	7.81
		15-30	71.92	10.38	2.76	14.94	S.L.	4.26	0.38	0.91	7.78
		30-45	68.72	13.70	3.71	13.87	S.L.	4.15	0.25	0.68	7.88
		45-60	57.60	24.93	3.60	13.87	S.L.	2.92	0.30	0.60	7.86
Mean			66.68	15.93	3.41	13.96	L.S.	3.76	0.34	0.80	7.83

Non-Cult. : Non-Cultivated Soil
S.W. : Sewage Water
Canal : Canal Water as Control
L. S. : Loamy Sandy
S. L. : Sandy Loamy
S.C.L. : Sandy Clay Loamy

The organic matter contents in soil irrigated with canal water is relatively very low compared to the soil irrigated with sewage water. These insure the role of sewage water in organic matter enrichment.

Data (Table 3) shows that using sewage water for irrigation reduced the pH of soil. The average pH was 7.83 for non-cultivated soil, it decreased to 6.47, 6.12, 6.09 and 6.07 in the soil irrigated with sewage water for 7, 12, 23, and 40 years, respectively.

3.3. METALS IN SOIL IRRIGATED WITH WASTEWATER (DTPA EXTRACTION)

According to some investigators (Lindsay and Norvell, 1978; Abdel-Shafy and Troeger, 1998) the DTPA procedure is usually used to determine the available soluble metals to the plant from the soil. Table (4) clearly indicates that the level of metals in the soil increased according to the period of sewage irrigation. Such increases were remarkably pronounced for the topsoil layer (0-15 cm) and slightly decreased by increasing soil depth. These results are in good agreement with that previously reported (Mansour, 1996; Abdel-Shafy et. al, 2003). This fact is true for the three types of soil. The level of metals in all the studied soils can be arranged according to the following decreasing order:

40 yr > 23 yr > 12 yr > 7 yr > soil irrigated by canal water > non-cultivated soil.

Finally, the decrease in metal contents according to depth increase was clearly indicated by Cu followed by Pb, Cd, Co and Cr. It is worth to stress here that although the sewage water was used for irrigation, but such soil contains much higher metals than other soil, which was irrigated by canal water for much longer periods at both of El-Gabal El-Asfar regions.

According to Egyptian Environmental Protection Agency (1994), the contents of the different elements in soil are ample but not excessive or toxic. This result is consistence with Mansour, 1996; Abdel-Shafy et. al, 2003).

3.4. METALS ELIMINATION USING LIME OR MIXING WITH DRIED PLANT

The effect of using dried and grinded plant leaves (as Water Hyacinth) for the uptake of metals is shown in Fig.(1). Results showed that the 1.0 g/l is the optimum dose at which elimination of Pb, Cd, Ni, Zn, Co, and Cr was 39, 23, 27, 44, 15 and 22% respectively. It is worth mentioning that such elimination is not satisfactory. However, the sludge of this method will contain dried plant

TABLE 4 Available heavy metals content as extracted by DTPA in soil irrigated with sewage water for different periods at El-Gabal El-Asfar sewage Farm

Period of Cultivated Years	Type of Water	Soil depth (cm)	(mg/Kg Soil) DTPA								
			Fe	Cu	Mn	Zn	Pb	Cd	Ni	Co	Cr
0	Non-Cult.	0-15	10.52	0.851	1.985	2.152	0.211	0.041	0.521	0.081	0.011
		15-30	8.23	0.482	0.984	1.392	0.135	0.018	0.360	0.045	0.011
		30-45	4.82	0.384	0.546	0.910	0.095	0.009	0.285	0.021	0.006
		45-60	3.18	0.064	0.382	0.508	0.031	0.009	0.090	0.018	0.002
Mean			3.309	0.324	0.720	0.707	0.075	0.015	0.179	0.029	0.004
7	S.W.	0-15	26.72	6.791	17.05	21.62	6.200	0.249	1.317	0.482	0.231
		15-30	23.49	4.591	10.81	12.43	2.641	0.150	1.110	0.215	0.103
		30-45	18.48	2.649	3.18	11.11	0.338	0.058	0.227	0.103	0.098
		45-60	12.05	0.629	2.64	5.99	0.135	0.032	0.190	0.071	0.012
Mean			6.396	2.638	6.857	6.511	2.820	0.099	0.587	0.187	0.090
12	S.W.	0-15	36.99	6.801	18.43	22.34	6.317	0.316	2.621	0.551	0.367
		15-30	25.88	4.782	13.67	17.31	4.510	0.211	1.352	0.215	0.122
		30-45	18.93	2.817	9.213	12.54	1.362	0.069	0.417	0.112	0.108
		45-60	12.40	0.754	4.516	6.280	0.201	0.035	0.211	0.075	0.025
Mean			10.52	2.596	5.965	6.849	2.814	0.130	1.099	0.217	0.147
23	S.W.	0-15	52.59	9.22	20.35	21.42	8.817	0.390	2.681	0.581	0.385
		15-30	34.98	7.13	13.93	15.03	5.013	0.218	1.031	0.262	0.128
		30-45	20.62	2.14	13.22	13.25	1.465	0.039	0.500	0.177	0.109
		45-60	17.16	0.734	9.14	8.63	0.240	0.035	0.252	0.061	0.031
Mean			16.13	4.024	4.635	5.297	3.862	0.169	1.093	0.223	0.154
40	S.W.	0-15	61.02	13.45	35.61	43.78	11.74	0.420	2.831	0.921	0.411
		15-30	46.45	10.32	23.80	25.40	6.081	0.225	1.211	0.742	0.161
		30-45	27.33	3.18	15.63	17.65	1.613	0.065	0.631	0.254	0.122
		45-60	17.99	1.54	10.12	13.27	0.344	0.039	0.300	0.136	0.042
Mean			19.28	5.685	11.08	13.47	5.155	0.176	1.123	2.053	0.159
50	Canal	0-15	17.31	1.985	6.851	2.921	0.851	0.171	0.985	0.245	0.192
		15-30	16.84	0.900	3.810	2.851	0.790	0.135	0.632	0.217	0.121
		30-45	15.32	0.721	3.121	1.951	0.312	0.027	0.501	0.181	0.092
		45-60	10.65	0.317	1.098	0.982	0.092	0.022	0.375	0.084	0.055
Mean			15.03	0.713	2.384	0.910	0.369	0.076	0.263	0.070	0.058

DTPA : Diethylene triamine penta acetic acid
Non-Cult. : Non-Cultivated Soil
S.W. : Sewage Water
Canal : Canal Water as Control

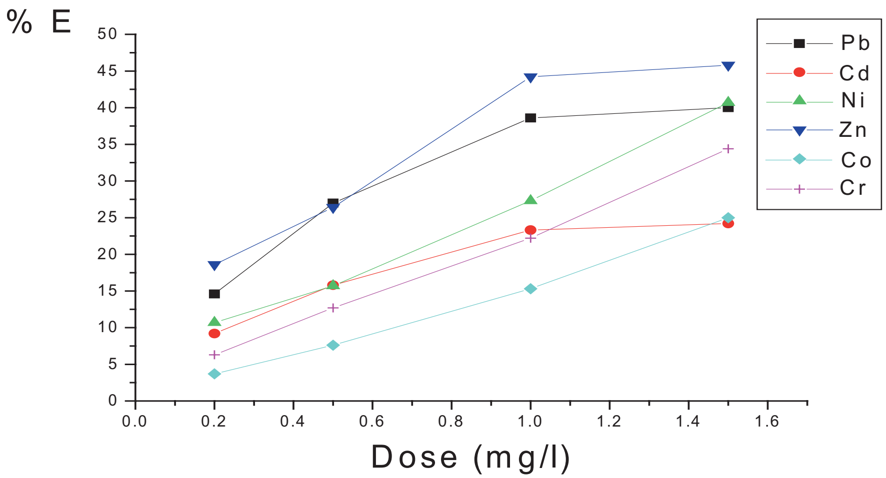

Figure 1 Effect of variable doses of dried Water Hyacinth plant on metals elimination from sewage water.

residue which considers enrichment and fertile to the soil due to the fact that it is natural organic origin. The use of such sludge can be evaluated as less risky than conventional sludge.

On the other hand, the use of lime (CaO) showed that 80 mg/l is the optimum dose, at which the removal rate of metals ranged from 49 to 97% Fig. (2). Therefore, lime has the advantages over the dried plant leaves for the removal of metals from sewage water.

4. Conclusion

- The use of treated sewage water on sandy soil has an advantage of: improving soil texture in terms of organic enrichment, macro- and micro nutrient elements.
- Remarkable increase in the level of heavy metals was observed. The longer term of irrigation the higher accumulation of metals particularly on the top soil.
- Level of heavy metals decreases as soil depth increases.
- Nevertheless, accumulation of metals on the soil was still far behind the risky level. This is mainly due to the fact that the level of metals in sewage irrigation water was within the permissible level according to WHO.
- To eliminate the accumulation of metals on the soil, it is, therefore, recommended to use an additional treatment process such as addition of dried plant leaves or lime to decrease the level of metals in the sewage irrigation water.

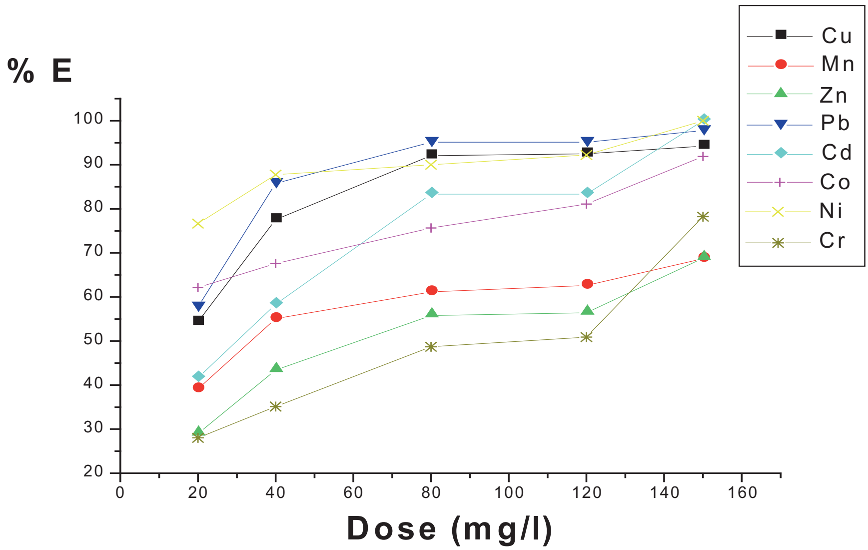

Figure 2 Level of heavy metals in sewage water of El-Gabal El-Asfar after chemical coagulation using lime (CaO)

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MEMBRANES FOR UNRESTRICTED WATER REUSE

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Abstract. Water reuse is becoming a key component of the water cycle management.The provision of sufficient and safe water supplies for human and environmental needs is a difficult challenge in many parts of the world, especially in arid regions. In order to manage water resources in an efficient and sustainable way, a wide range of tools and techniques are required. Water recycling and reuse is an increasingly important element of sustainable water management strategies in both water poor and water rich regions. Municipal wastewater, which comprises between 60-80% of municipal water consumption, is one of the most reliable sources of water, since municipal water supply is always of high priority. If treated properly, it can replace potable water and used for unrestricted irrigation, including edible crops. Membrane separation processes such as ultrafiltration (UF) and microfiltration (MF) hold the key to better water treatment as tertiary filtration, after existing biological treatment. Careful evaluation of engineering aspects of these filtration technologies will yield design and operation parameters for applications in Europe. A few case studies will be presented. Economic analysis was carried out, for a system that produces a net effluent capacity of 25,000m^3/day, resulted in a total cost of 8-10 cent per cubic meter. Recently, Membrane Bioreactor Systems (MBR) are becoming an attractive alternative, especially for limited space constrains, taking into advantage their smaller footprint, as compared to conventional wastewater systems. Also, the higher qualities of their effluent, with SDI values lower than 3, indicate the suitability of the process for pre-treatment for desalination by Reverse Osmosis, for effluents with high salinity. The concept of Integrated Membrane Systems (IMS) will be elaborated, and case studies will be described.

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Keywords: agriculture; membrane processes ; microfiltration ; ultrafiltration, unrestricted water reuse.

1. Importance of Water Reuse

Water reuse is a key component of both total water cycle management and integrated water resource management. These approaches aim to manage all of the components of the hydrological cycle (rainwater, stormwater, wastewater, groundwater, surface water and recycled water) to secure a range of social, economic and environmental benefits.

The provision of sufficient and safe water supplies for human and environmental needs is a significant and difficult challenge in many parts of the world. In order to manage water resources in an efficient and sustainable way, a wide range of tools and techniques are required. Consequently, water recycling and reuse is an increasingly important element of sustainable water management strategies in both water poor and water rich regions. The key to successful implementation of reuse is user acceptance (Jeffrey, 2002) and the assessment of risk. Psychological and religious aspects have to be taken in consideration. As a consequence, treated wastewater should not be used as potable, only in extreme circumstances, even when the quality of the treated effluent can be defined as suitable for accidental drinking. Risk analysis plays an important role in municipal reuse schemes, as well as in unrestricted agricultural reuse. Most of these concepts were addressed in a recent three-year EU project, AQUAREC, (EVK1-CT-2002-00130) and are reported elsewhere.

2. Environment and Public Health

From environmental and public health concerns, it is critical to treat municipal effluents to the highest level, by best available techniques. These include removal of suspended solids, microbial contaminants, nutrients and trace dissolved contaminants, such as endocrine disruptors. If treated effluents are to be used for unrestricted agricultural use (Brenner, 2000), there is further need to remove common dissolved salts as well as boron, for example, which is well documented as having detrimental effects on certain crops and besides from occurring in some natural groundwaters, it is commonly found in laundering and dishwasher powders, thus finding its way to municipal wastewater.

3. Membrane Processes

Membrane processes are designed to carry out physical and physico-chemical separations. Pressure-driven membrane separation processes are primarily based on size-exclusion. Microfiltration membranes (MF) have pore sizes in the range of 0.2-0.4 microns, while ultrafiltration membranes (UF) range from 1 to 100 nm. They are capable of retaining species in the molecular weight range of 300 to 500 kDaltons. Both types can meet, in principle, the advanced effluent treatment objectives listed above, including removal of viruses. These may be smaller than the nominal pore sizes described above, however, but they are totally rejected because they are attached to larger suspended particles that are easily separated by the membranes. Nanofiltration (NF) membranes which have pore sizes in the range of one magnitude lower than ultrafiltration are recommended for removal of organic compounds and polyvalent salts. Only when the effluents contain a large concentration of salts, usually defined as above 250-350 mg/l chlorides, it is recommended to use reverse osmosis (RO) processes that are highly effective to remove also trace organic contaminants.

These membrane processes are applied after conventional secondary treatment, such as activated sludge and clarification, and they are referred as CAS-TF: conventional activated sludge tertiary filtration. An important aspect of membrane processes is the constant quality of the permeate, independent of environment conditions, whether it is winter or summer. An example of typical raw sewage characteristics and effluent quality after Ultrafiltration are described in Tables 1 and 2. These experiments were carried out in a municipal wastewater treatment plant (WTTP) in Ashkelon, Israel, where a pilot-plant of Zenon ZeeWeed 500c (Zenon, Canada) with three cassettes of immersed hollow fibers having a surface area of 35 m^2 each, treated effluent after activated sludge (CAS-TF), for a period of two years, 2001-2003. Figures 1 and 2 show that the effluent turbidity was below 0.1 NTU, both in summer and winter, even though storm waters arrived to the WTTP during the winter season and contributed to the high turbidities of the effluent, after the activated sludge process, about 100 NTU, (Uzan-Silner, 2003). The pilot-plant is seen in Fig.3, below.

TABLE 1 Raw sewage characteristics

BOD5	250-300 mg/L
Total Nitrogen	35-45 mg/L
Total Suspended Solids	250 mg/L
Total Phosphorus	8-12 mg/L

TABLE 2 Effluent Quality

BOD5	< 5 mg/L
Ammonia-Nitrogen	< 1 mg/L
Total Nitrogen	< 10 mg/L (moderate climate)
	< 3 mg/L (hot climate)
Turbidity	< 0.5 NTU
Total Suspended Solids	< 5 mg/L
Total Phosphorus	< 0.1 mg/L (with chem. addition)
SDI	< 3
Fecal Coliforms	< 10 CFU/100 mL

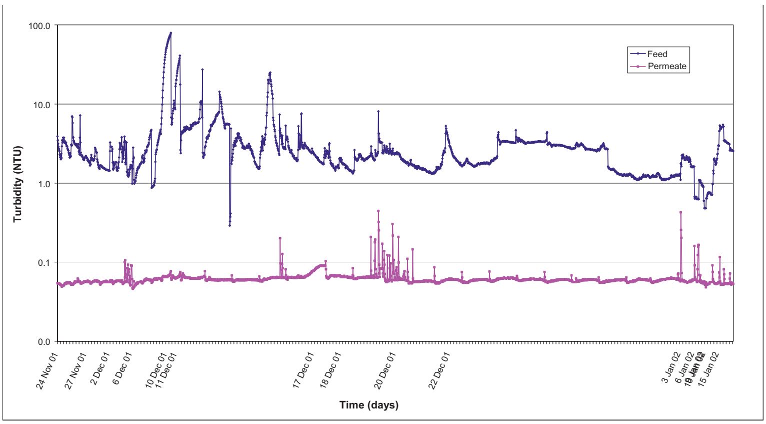

Figure 1 Feed and Permeate turbidity during winter

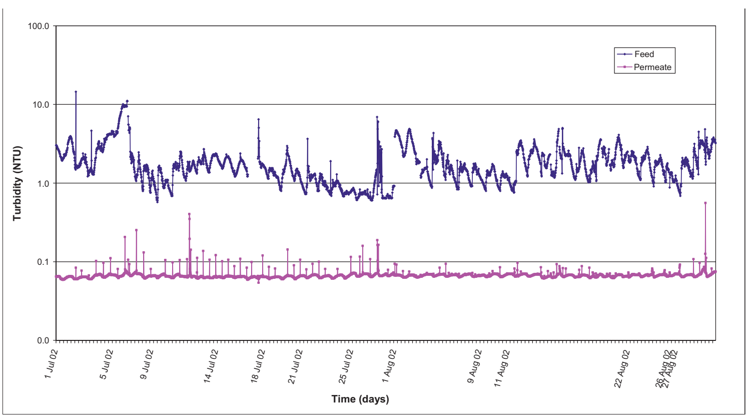

Figure 2 Feed and Permeate turbidity during summer

Figure 3 Pilot-plant in WTTP, Ashkelon, Israel

4. Desalination of Municipal Effluent for Water Reuse

In many arid and semi-arid regions, such as Israel, the salinity of municipal effluents can reach high values, about 300-350 mg/l. Since most of treated effluents are replacing fresh, potable and scarce water for agricultural purposes, various crops may be affected by common salts, after CAS-TF treatment alone. Further treatment by RO for complete removal of salts is required. Experiments were carried out, treating sewage at the municipal WTTP in Beer-Sheva, Israel, (Messalem, 2000). The results showed that the treatment is economical, even at 70 % recovery. Recently, an economic analysis (Cote, 2004) has shown that the ratio of desalination of CAS-TF effluent to seawater is about 2.5. This ratio can increase if the recovery of desalinated effluent can reach 90%, instead of 50% with seawater (Glueckstern, 2002). A large pilot-plant is being installed in the Shafdan site, Israel, to further check these assumptions and carry out performance optimizations, in collaboration with the Ben-Gurion University of the Negev.

5. Membrane Bioreactor

In the last years, integrated membrane bioreactors (MBR) have made their appearance. They replace the whole treatment train (CAS-FT) by a single process, using immersed membranes in the form of hollow fibers (Zenon, Canada) or flat sheet (Kubota, Japan), installed directly in the reactor in which the aerobic biological step is carried out, (Fig. 4). Aeration is supplied constantly for the biological process and for the prevention of a cake layer of suspended solids against the immersed membranes. These systems take into advantage their smaller footprint, as compared to conventional wastewater systems. A very large plant, 42 MLD (million liters per day) was built in Bedok, Singapore. It is an excellent example of achieving effluent of drinking water quality from sewage. The MBR process, compared to CAS-FT, runs at higher suspended solids concentrations, longer SRT and less susceptible to upsets; this leads to better biodegradation of soluble organic compounds, (Cote, 2004).

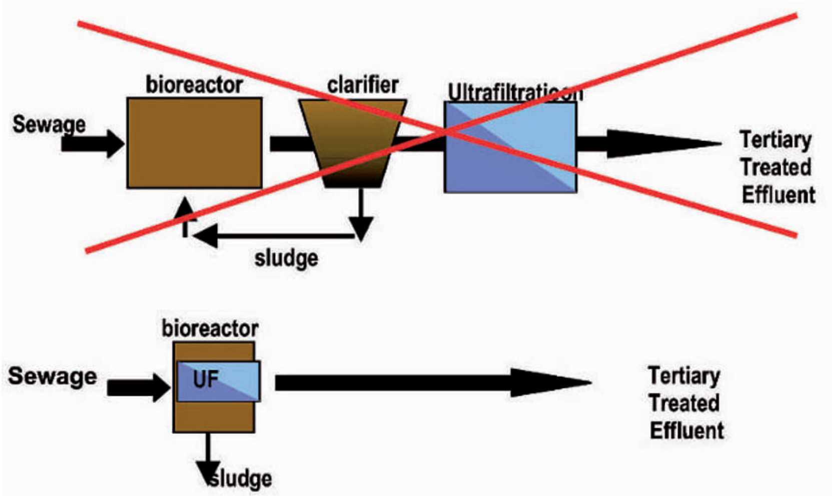

Figure 4 Process flow diagram for the Membrane Bioreactor

6. Economic Evaluation

Membrane processes have been an integral part of the chemical industry for the last 40 years, in specific areas. Better polymeric membranes, more inert and stable to harsh cleaning conditions and extreme pH environment, were developed. Improved transport processes, membrane module design together with computerized control brought about an exponential increase in membrane plants, in the last 15 years, (Fig. 5). Consequently, membranes and plant installation costs decreased, (figs. 6, 7) and can compete effectively with conventional wastewater treatment systems, (Cote, 2005), thus making it economical to treat sewage to the highest level, for unrestricted agricultural water reuse.

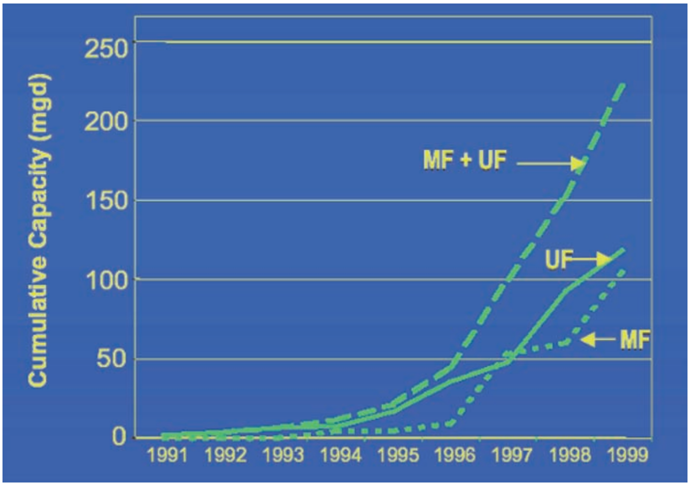

Figure 5 Cumulative capacity (Courtesy of CH2M Hill)

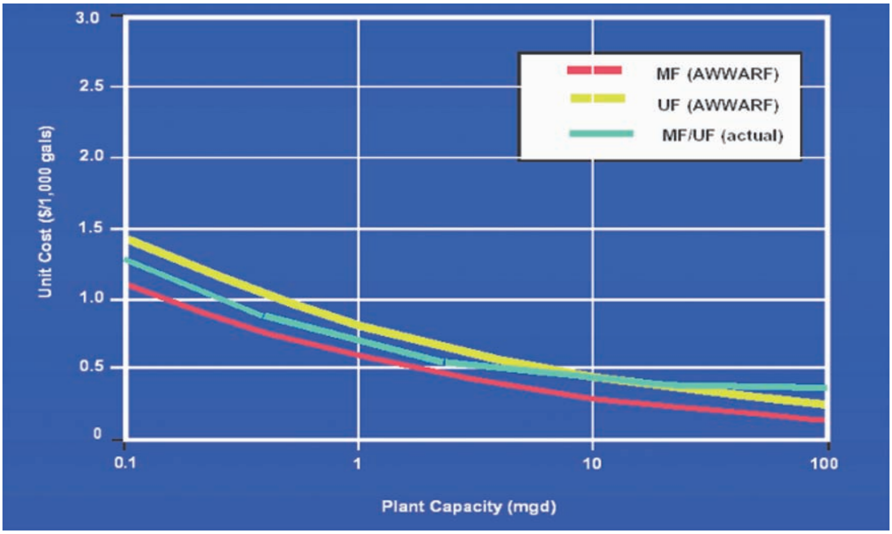

Figure 6 Decreasing membrane Cost (Courtesy of CH2M Hill)

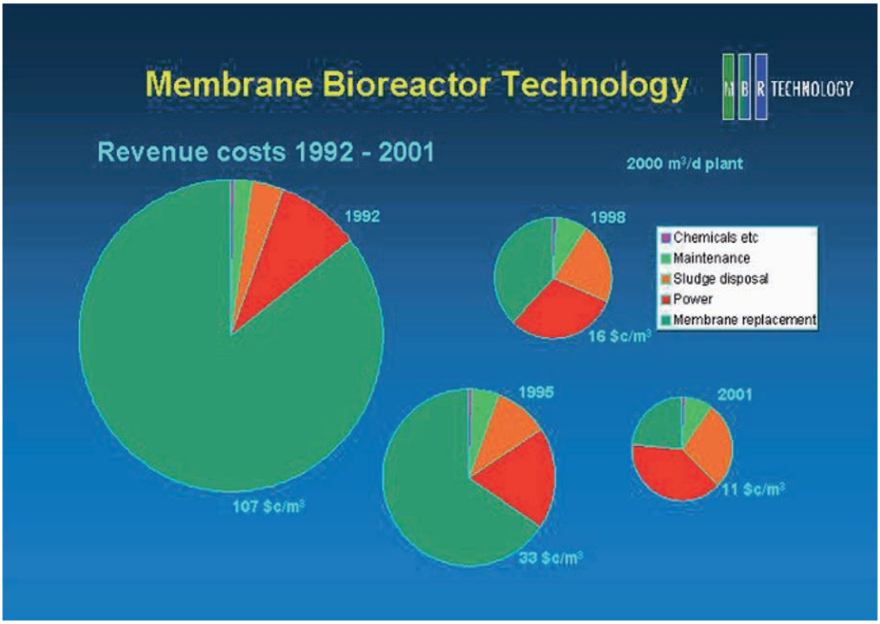

Figure 7 Decreasing MBR Cost (Courtesy of MBR Technology)

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SUBJECT INDEX

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