Integrated Water Cycle Management in Kazakhstan

Tempus



Integrated Water Cycle Management in Kazakhstan

Editors:

Burghard C. Meyer

Leipzig University, Germany

Lian Lundy,

Middlesex University, London, UK

Textbook developed in the TEMPUS IV – 5th Call of Proposals on Joint Projects

I-WEB™

Almaty

"Qazag university"

2014

Editors:

Burghard C. Meyer & Lian Lundy,

The publication should be citated as follows

Meyer B. C. & L. Lundy (Eds). 2014. Integrated Water Cycle Management in Kazakhstan. Al-Farabi Kazakh National University, Publishing House, Almaty, 320 pages

ISBN: 978-601-04-0900-2

Published with active contributions of the TEMPUS IV IWEB-Project partner's institutions:

- Middlesex University, London, UK
- Al-Farabi Kazakh National University, Almaty, Kazakhstan
- Ahmed Yasawi International Kazak-Turkish University, Turkistan, Kazakhstan
- Kokshetau State University named after Shokan Ualikhanov, Kokshetau, Kazakhstan
- Universität Leipzig, Germany
- Universitat Politecnica de Valencia, Spain
- University of Cyprus, Nicosia, Cyprus
- Institute of Geography of the Republic of Kazakhstan, Almaty, Kazakhstan
- The Regional Environmental Centre for Central Asia, Almaty, Kazakhstan
- Kazakh Scientific Research Institute of Water Economy, Taraz, Kazakhstan
- Kazakh Research Institute of Fishery, Almaty, Kokshetau, Kazakhstan
- Institute of Professional Development and Retraining, Kokshetau, Kazakhstan
- Ministry of Education and Science Control Committee, Astana, Kazakhstan
- Center of Bologna process and academic mobility, Astana, Kazakhstan
- Fund Zhas Otan, Akmola region, Kokshetau, Kazakhstan

Cover page photographs: Burghard Meyer

Authors Index

List of contributing authors and contact details, together with identification of **sub-chapters (co-) authored**.

Abdullaev, Iskandar, the Regional Environmental Centre for Central Asia, CAREC, 40, Orbita-1, Almaty, 050043, Republic of Kazakhstan: IAbdullaev@carececo.org; 3.2, 7.1, 7.3.
Akbassova, Amankul; H.A.Yassawi International Kazakh-Turkish University, Ecology and Chemistry Department, Ecology Research Institute, 29, B. Sattarkhanov Avenue, Turkestan, 161200, Kazakhstan, ecolog_kz@mail.ru; 4.9.
Andreu, Joaquín, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain; ximoand@upv.es; 2.3, 2.4, 2.5, 2.6.
Artsanov, Rustam, the Regional Environmental Centre for Central Asia, CAREC, 40, Orbita-1, Almaty, 050043, Republic of Kazakhstan: rarstanov@gmail.com; 7.1.
Asylbekova Saule, Kazakh Fisheries Research Institute, district -12, 1/1, Almaty, 050036, Kazakhstan. assylbekova@mail.rug; 5.9, 7.2.
Bayeshov, Abduali; D.V.Sokolsky Institute of Organic Catalysis and Electrochemistry, 142, Str. D. Kunaev, Almaty, 050010, Kazakhstan, bayeshov@mail.ru; 4.8.
Bazarbayeva, Tursynkul; Al-Farabi Kazakh National University, Energy and Ecology Department, 71. Al-Farabi Avenue, Almaty, 050040, Kazakhstan, nur_tyr2301@mail.ru; 6.3.
Bekbayev, Rahim; Kazakh scientific research institute of water economy, 12, Koigeldy Str, Taraz, 080003, Kazakhstan, bekbayev_55@mail.ru; 5.11.
Burkitbayev, Mukhambetkali; First Vice-Rector; Al-Farabi Kazakh National University, Al Farabi Avenue, Almaty, 050040, Kazakhstan, mukhambetkali.burkitbayev@kaznu.kz; Foreword.
Charré, Simon, Branch Office of the Regional Environmental Centre for Central Asia in the Kyrgyz Republic, 10 Erkindik Bul., Bishkek, 720040, Kyrgyz Republic, scharre@carececo.org; 7.1.
Dostay, Zhakypbay; Institute of Geography JSC National Scientific and Technological Holding Company "Parasat", Department of Water resources, Kabanbai batyr st./Pushkin st. 67/99, Almaty, 050010, Kazakhstan, zh.dostai@mail.ru; 5.4.
Dougall, Anne; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, A.Dougall@mdx.ac.uk; 3.7.
Duskayev, Kassym; Al-Farabi Kazakh National University, Meteorology and Hydrology Department, 71. Al-Farabi Avenue, Almaty, 050040, Kazakhstan, kduskaev@gmail.com; 5.1, 5.3, 6.2, 6.3, 6.4.
Fatta-Kassinos, Despo, Nireas-International Water Research Center, School of Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus: dfatta@ucy.ac.cy; 4.1, 4.2, 4.3, 4.4, 4.5.
Garelick, Hemda; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, H.Garelick@mdx.ac.uk; 1,2, 2.7, 2.8, 3.7.
Hapeshi, Evroula, Nireas-International Water Research Center, School of Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus, hapeshi.evroula@ucy.ac.cy; 4.1, 4.2, 4.3, 4.4, 4.5.
Haro, David, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain. dahamon@upv.es; 2.4.
Hofner, Simone, United Nations Economic Commission for Europe, Palais des Nations, 1211 Geneva 10, Switzerland: simone.hofner@unece.org; 3.8.
Inozemtseva, Anna, the Regional Environmental Centre for Central Asia, CAREC, 40, Orbita-1, Almaty, 050043, Republic of Kazakhstan: AInozemtseva@carececo.org; 3.5.
Isbekov Kuanish, Kazakh Fisheries Research Institute, Mamur-3, 21/42, Almaty, 050036, Kazakhstan. isbekov@mail.ru; 5.9; 7.2.
Jones, Huw; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, H.Jones@mdx.ac.uk; 2.7, 2.8, 3.4.
Kakabayev, Anuarbek; Sh. Ualikhanov Kokshetau State University, Geography and Ecology Department, 76, Abay Street, Kokshetau, 020000, Kazakhstan, anuarka@mail.ru; 5.10.
Kazangapova, Nurgul; Sh. Ualikhanov Kokshetau State University, Chemistry and Biotechnology Department, 76, Abay Street, Kokshetau, 020000, Kazakhstan, kazangapova@bk.ru; 5.5, 5.7.
Kurbaniyazov, Abilgazy; H.A.Yassawi International Kazakh-Turkish University, Ecology and Chemistry Department, 29, B. Sattarkhanov Avenue, Turkestan, 161200, Kazakhstan, abylgazy.kurbanyazov@iktu.kz; 5.6.

Lapuente; Enrique, IIAMA, I, Universitat Politècnica de València, Cno. De Vera s/n, 46022 Valencia, Spain, enlaoj@hma.upv.es; 1.3, 1.4.
Lerma, Néstor, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain, nestorlerma@upv.es; 2.3.
Lundy, Lian; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, L.Lundy@mdx.ac.uk; Editor, Introduction, 1.1, 1.5, 3.6, 6.1, 7.4; Glossary.
Martin, Miguel, IIAMA, I, Universitat Politècnica de València, Cno. De Vera s/n, 46022 Valencia, Spain, mmartin@hma.upv.es; 1.3, 1.4.
Meyer, Burghard, Leipzig University, Institute of Geography**.** Johannisallee 19a, 04103 Leipzig, Germany. Burghard.meyer@olanis.de; Editor, Introduction, 1.6, 2.2, 3.3, 5.2, 5.3, 6.1, 7.4; Glossary, Index.
Michael, Irene, Nireas-International Water Research Center, School of Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus, michael.irene@ucy.ac.cy; 4.1, 4.2, 4.3, 4.4, 4.5.
Minzhanova, Guldana; Al-Farabi Kazakh National University, Energy and Ecology Department, 71. Al-Farabi Avenue, Almaty, 050040, Kazakhstan, guldana.m@mail.ru; 5.1, 6.2, 6.3, 6.4.
Molina. Jose luis Alonso, Research Institute of Water and Environmental Engineering, Universitat Politecnica de Valencia, Cno. de Vera s/n, 46022 Valencia, Spain. jalonso@ihdr.upv.es; 1.2.
Momblanch, Andrea, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain; anmombe@upv.es; 2.5.
Nurdillayeva, Raushan; H.A.Yassawi International Kazakh-Turkish University, Ecology and Chemistry Department, 29 B. Sattarkhanov Avenue, Turkestan, 161200, Kazakhstan, raushan.nurdillayeva@iktu.kz; 4.7, 4.8.
Nurmukhanbetova, Nurgul; Sh. Ualikhanov Kokshetau State University, Chemistry and Biotechnology Department, 76, Abay Street, Kokshetau, 020000, Kazakhstan, nn_nurgul@mail.ru; 5.5.
Paredes-Arquiola, Javier, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain; jparedea@hma.upv.es; 2.3, 2.4, 2.5, 2.6.
Pedro-Monzonis, María, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain. mapedmon@hotmail.com; 2.3; 2.6.
Purchase, Diane; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, D.Purchase@mdx.ac.uk; 1.2.
Pyatov, Evgeniy; JSC “Kokshetau mineral water”, Vice President of Science, North Industrial Area, PO Box 926, Kokshetau, 02000, Kazakhstan, pyatov@yandex.ru; 4.6.
Rakhmatullaev, Shavkat, National water Management expert of the Transboundary water management in Central Asia/German International Cooperation (GIZ), Republic of Uzbekistan: shavkat.rakhmatullaev@giz.de; 3.2.
Romanova, Sofia; Al-Farabi Kazakh National University, General and Inorganic Chemistry Department, 71, Al-Farabi avenue, Almaty, 050000, Kazakhstan, vivarom@mail.ru; 5.5, 5.7.
Salnikov, Vitaliy; Al-Farabi Kazakh National University, Meteorology and Hydrology Department, 71, Al-Farabi Avenue, Almaty, 050040, Kazakhstan, vitali.salnikov@kaznu.kz; 5.3.
Schmidt Ronny, Leipzig University, Institute of Geography. Johannisallee 19a, 04103 Leipzig, Germany. ronny.schmidt@uni-leipzig.de; 1.7.
Schneider, Christian, Leipzig University, Institute of Geography. Johannisallee 19a, 04103 Leipzig, Germany. christian.schneider@uni-leipzig.de; 1.7, Index.
Schreiner, Vera, Leipzig University, Institute of Geography**.** Johannisallee 19a, 04103 Leipzig, Germany. Vera_schreiner@yahoo.de; 5.2.
Shakirova, Tatiana, the Regional Environmental Centre for Central Asia, CAREC, 40, Orbita-1, Almaty, 050043, Republic of Kazakhstan: tshakirova@carececo.org; 3.8.
Shalgimbayeva Gulmira, Kazakh Fisheries Research Institute, Zarokova 269/52 Almaty, 050056, Kazahkstan. Shalgimbayeva@mail.ru; 5.9, 7.2.
Solera, Abel, IIAMA (Research Institute Of Water And Environmental Engineering), Universitat Politècnica de València, Cno. de Vera s/n, 46022 Valencia, Spain; asolera1@gmail.com; 2.3, 2.4, 2.5, 2.6.
Strikeleva, Yekaterina. the Regional Environmental Centre for Central Asia, CAREC, 40, Orbita-1, Almaty, 050043, Republic of Kazakhstan: estrikeleva@carececo.org; 3.5.
Toregozhina, Zhanna; Al-Farabi Kazakh National University, Energy and Ecology Department, 71. Al-Farabi Avenue, Almaty, 050040, Kazakhstan, zhan_tore@mail.ru; 6.4.

Toumazi, Toumazis, Nireas-International Water Research Center, School of Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus, toumazi.toumazis@ucy.ac.cy; 4.1, 4.2, 4.3, 4.4, 4.5.
Vasquez, Marlen Ines, Nireas-International Water Research Center, School of Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus, vasquez.marlen@ucy.ac.cy; 4.1, 4.2, 4.3, 4.4, 4.5.
Watt, John; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, J.Watt@mdx.ac.uk; 2.1, 3.1, Introduction.
Wildeboer, Dirk; Middlesex University, Department of Natural Sciences, The Burroughs, Hendon, London, NW4 4BT, UK, D.Wildeboer@mdx.ac.uk; 2.7, 2.8.
Zavialov, Peter; P.P.Shirshov Institute of Oceanology, Laboratory of land-ocean interactions and the anthropogenic impact, 36, Nakhimovski Avenue, Moscow, 117997, Russia, peter@ocean.ru; 5.6.
Zhanabayeva, Zhanara; Al-Farabi Kazakh National University, Meteorology and Hydrology Department, 71. Al-Farabi Avenue, Almaty, 050040, Kazakhstan, zhanusik9@mail.ru; 6.2.
Zhaparkulova, Ermekul; Kazakh scientific research institute of water economy, 12, Koigeldy Str, Taraz, 080003, Kazakhstan, ermekull@mail.ru; 5.11.
Zharkinbekov, Temirkhan; Sh. Ualikhanov Kokshetau State University, first vice-rector, 76, Abay Street, Kokshetau, 020000, Kazakhstan, zharkinbekov_t@mail.ru; 5.8.
Zhylysbayeva, Akkongyr; H.A.Yassawi International Kazakh-Turkish University, Ecology and Chemistry Department, 29, B. Sattarkhanov Avenue, Turkestan, 161200, Kazakhstan, akkonyr@mail.ru; 4.7, 4.8.

Table of contents

Chapter 1

Selected Concepts in Integrated Water Cycle Management

1. Selected concepts in IWCM

1.1 Water bodies as providers of multiple ecosystem services, goods and benefits

Lian Lundy

E-mail address: L.Lundy@mdx.ac.uk

Introduction

This sub-chapter introduces the concept of ecosystem services; the delivery of goods and benefits by the environment on which humans depend. Key terms are defined and a framework for categorising ecosystem services described. The outcomes of the Millennium Ecosystem Assessment (MEA, 2005) - the major global study which brought the concept to international attention - are presented. Links between integrated water cycle management and ecosystem services concepts are briefly elaborated and an overview of the ecosystem services, goods and benefits which may be delivered by water bodies presented.

The ecosystem services concept

An ecosystem can be defined as a complex, dynamic relationship between plants, animals, micro-organisms and the non-living environment which interact as a functional unit (MEA, 2005). Ecosystems do not have fixed boundaries, as what constitutes a functional unit depends on the issue being evaluated. Hence, ecosystems can vary greatly in size; from the surface waters of a transient rain puddle (if examining the colonisation behaviour of micro-organisms) to an ocean (if evaluating the migratory behaviour pelagic fish) to the entire planet (e.g. if focussing on the impact of humans on water resources). Within this broad flexible context, our whole world can essentially been seen as a complex mosaic of inter-related ecosystems functioning over multiple scales.

The term ecosystem services refer to the provision of goods and benefits by the environment on which humans depend (UK NEA, 2011). There are several approaches to classifying ecosystem services but the approach most commonly used is the framework utilised within the Millennium Ecosystem Assessment (MEA, 2005) and many authors in a variety of contexts since (e.g. Lundy and Wade, 2011). The MEA framework divides the services provided by the environment which benefit people into four broad categories as follows:

- Supporting services are the bio-physico-chemical processes which underpin the delivery of all other category of services e.g. oxygen production, soil formation. Their impacts on humans are often indirect and/or occur over very long periods of time.
- Regulating services are the goods and benefits generated through the regulation of ecosystem functions including processes such as climate regulation and pollination.
- Provisioning services refer to the production of products from ecosystems, including fuel and fibre.
- Cultural services refer to the non-material benefits generated by ecosystems such as spiritual values and opportunities for recreation.

An overview of each of the different types of ecosystem services within each category is presented in Table 1.1.1, together with examples of the goods and benefits associated with each service. The delivery of many, if not all, ecosystem services, goods and benefits are interlinked, with many interdependencies (MEA, 2005). For example, the delivery of provisioning, regulating and cultural services are all dependent on the delivery of a range of supporting services. For example, all life is dependent on the functioning of the water cycle. The outputs of many of the regulating services (e.g. pollination) contribute to the delivery of provisioning services such as fruit and vegetables which generate many of the human necessities of life. It should also be noted that some goods and benefits could be categorised under more than one type of service category e.g. carbon sequestration can be both a regulating and provisioning service. Our current approach to managing ecosystems tends to maximise the delivery of provisioning goods and benefits (e.g. fuel and water), key aspects which are characteristically linked to cultural goods and benefits we value e.g. water and forest-scapes as areas of natural beauty.

The Millennium Ecosystem Assessment: key findings

Initiated in 2001, the MEA was an ambitious four-year project involving over 1300 scientists from a range of disciplines working collaboratively. Its key aim was to evaluate links between ecosystems services and human health using the language of ecosystem services and to identify how changes in the environment would impact on our well-being. It reported that not only are humans dependent on a range of ecosystem services for clean air, water, food and fuel but that damage to the environment is seriously degrading its ability to provide these services (MEA, 2005) (see Box 1 for the main findings of the MEA).

The MEA (2005) was the key study that brought the concept of ecosystem services to international attention. Its stark conclusion is that our current life-style choices are depleting the Earth's finite resources to the extent that the ability of our environment to continue to generate and deliver the ecosystem services, goods and benefits on which we all depend is no longer assured. Whilst the results of the assessment suggested that, with major efforts and changes in current policies and practices, it is still possible to reverse the degradation of some ecosystem services, such changes have yet to be implemented.

Table 1.1.1 An overview of the MEA ecosystem services framework together with examples of ecosystem goods and benefits they provide (adapted from Lundy and Wade, 2011)

Categories of ecosystem services	Types of ecosystem services	Ecosystem goods and benefits
Supporting services	Primary production Production of oxygen Soil formation Water cycling Provisioning of habitat	Supporting services underpin the delivery of provisioning, regulating and cultural services.
Provisioning services	Food Water Fibre Fuel Renewable energy Carbon sequestration Genetic resources	Meat, fish, fruit and vegetables Potable and non-potable water from rivers, lakes and groundwater Cotton, wool Peat, coal, gas, wood, bio fuels Hydro, wind and solar power Reduction in levels of C in the atmosphere Antibiotics and other natural medicines, pollutant degrading species as a resource for current and future generations.
Regulating services	Climate regulation. Disease/pest regulation Pollination Water regulation Erosion control Water purification	Carbon sequestration, biogas regulation, reduced urban temperatures, enhancement of air quality Resilience to invasive species Fertilisation of crops and fruits Reduced runoff volume / velocity Stabilisation of sediments Removal of pollutants
Cultural services	Spiritual value Educational value Aesthetics Recreation Tourism	Mental well being Increased environmental awareness Increased house prices Physical well being Local jobs and economic growth

Integrated water cycle management and ecosystem service delivery

Whilst using different languages, the concepts of integrated water cycle management (IWCM) and ecosystem service delivery have many commonalities (Cook and Spray, 2012). Both concepts are underpinned by the recognition of water resources as an integral component of ecosystems, a natural resource and a social and economic good. Both seek to integrate the management of water, land and related resources aiming to maximise economic and social welfare without compromising ecosystem health. Furthermore, both concepts face the same key challenge (Cook and Spray, 2012); the implementation of this new and holistic way of thinking within current institutional frameworks. As a contribution to bridging the gap from theory to practice, the following sections go on to describe the multi-functional role of water bodies using the language of ecosystem services.

Water is present in a variety of natural (e.g. rivers, wetlands and groundwater), artificial (for example, canals and sustainable drainage systems) and 'hybrid' (e.g. restored rivers) forms which exist on a range of spatial and temporal scales (Lundy and Wade, 2011). As a contribution to the debate on integrated approaches to the management of water bodies, the following sections consider the multiple roles of water components in terms of the supporting, provisioning, regulating and cultural ecosystem services they can deliver.

Box 1. Key findings of the MEA (2005)

- Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.
- The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.
- The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals.
- The challenge of reversing the degradation of ecosystem while meeting increasing demands for services can be partially met under some scenarios considered by the MEA but will involve significant changes in policies, institutions and practices that are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services.

Supporting services

Examples of supporting services provided by water bodies range from primary production and water cycling to habitat provision (see Table 1.1.1). Primary production is at the base of all food chains, with aquatic vegetation estimated to contribute approximately 50% of this underpinning process on a global scale (Field et al., 1998). Aquatic vegetation also contributes to oxygen production, releasing oxygen to both the atmosphere and water bodies as an essential by-product of primary production (Nakova et al., 2009). Lakes, streams and rivers can all play a role in the formation and retention of alluvial soils and sediments. For example, soil accretion rates of 1mm - 1cm $year^{-1}$ have been reported for flood plains and coastal marshes, respectively (Saint-Laurent et al., 2008). Both surface and ground water bodies are key components of the water cycle and hence contributors to the provision of freshwater. For example, surface water bodies directly receive rainfall, they can act as sources and sinks for the movement of water through substrates into and from groundwater aquifers and also provide exposed surface areas from which water can evaporate back to the atmosphere. Water bodies also provide habitat for a wide range of flora and fauna. For example, recent estimates of the number of species on the planet suggest 8.7 million eukaryotic species globally, of which 2.2 million are marine (Mora et al., 2011).

Provisioning services

The provisioning services provided by water bodies include production of clean water, food (e.g. fish, shellfish and seaweed), energy (e.g. hydropower) and genetic resources (e.g. antibiotics) (see Table 1.1.1). Both local and distant surface and groundwater bodies routinely provide water supplies to meet a range of domestic, irrigation and industrial water needs. Water bodies provide a wide range of foods, from seaweeds to fish with the UN Food and Agriculture Organisation (FAO) estimating that 15-20 % of all animal proteins come from aquatic animals (UN FAO, undated). On a global basis, hydropower accounts for 19% of all electricity production, with China, Canada and Brazil amongst the largest producers of hydroelectricity

(USGS, 2010). Further provisioning services include the supply of genetic information used in animal and plant breeding, biochemicals (e.g. used for pharmaceuticals) and ornamental resources (e.g. flowers and shells) (MEA, 2005).

Regulating services

Water bodies contribute to the delivery of many of regulating services identified in Table 1.1.1 including water purification and erosion control. Whilst there are data sets available on the delivery of some identified services e.g. the role of rivers in enhancing local flood attenuation and reducing downstream flooding (EA, 2002), the potential for water bodies to provide a range of further regulating services, such as carbon sequestration, noise regulation and pollination is only beginning to emerge. This is partly associated with a lack of data pertaining to these aspects but also associated with the fact that such benefits have not yet necessarily been discussed in terms of ecosystem service provision. For example, water bodies are known to act as heat sinks offering the potential for urban water bodies to contribute to mitigation of the urban heat island effect. However, data sets or models to enable e.g. urban planners to specifically incorporate such functions to achieve specified temperature reduction benefits have yet to be developed. In urban contexts, water and associated vegetation (referred to as 'blue-green' features) can also contribute to a range of further planning and design philosophies including the provision of green infrastructure, urban greening and low impact development.

Cultural services

It has long been recognised that environments supply more than the necessities of food, water etc., but can additionally provide restorative and preventative health benefits (e.g. see review by Ward Thompson, 2010). In the context of tackling ever increasing health challenges (e.g. rising levels of obesity and mental illness reported in many countries (Pieniak et al., 2009), the role of water bodies in providing a relatively low-cost contribution to improving and maintaining physical and mental health has become a focus of attention for both researchers and policy. Research by White et al., (2010) reported that natural and built environments containing water are associated with higher preferences than either environment without water. Of particular interest is their finding that built environments containing water were as preferred as purely green space, suggesting that the presence of water confers some level of intrinsic value irrespective of location. Whilst larger water bodies can provide opportunities for recreational activities such as boating, canoeing and fishing, water bodies of all sizes provide attractive locations for more reflective and passive activities. For example, research on the social impact of stormwater management ponds (see Section 1.5) reported that residents living close to mature ponds not only valued the systems in terms of flood management but also their role in attracting wildlife and improving the landscape, with residents suggesting that homes located close to well-designed, managed, established BMPs would achieve a 10% premium (Apostolaki, undated).

Conclusion

Surface and groundwater bodies are providers of water, the stable requirement on which we all depend. However, water bodies can and do provide a whole host of services, goods and benefits which make a crucial contribution to human health and well-being on local to global scales. Evaluating water bodies using the language of ecosystem services supports the development of a multi-disciplinary understanding of the multiple benefits provided by a diverse range of water body types. Multi-disciplinary understanding is essential in supporting the development of integrated approaches to water cycle management. Hence the use of an ecosystem services framework in identifying services, goods and benefits associated with water bodies is seen as a valuable tool in supporting the development of a common understanding of the need for, requirements of and subsequent implementation of an integrated approach to water resource management.

1.2 Microbial pollution of water

Hemda Garelick, Diane Purchase and José Luis Alonso Molina

Email address: H.Garelick@mdx.ac.uk

Introduction

The Drinking Water Directive (80/778/EEC) and its revision (98/83/EC) which comes in force in 2003) aims to ensure that water intended for human consumption must be free of any microorganism, parasite or substance that could potentially endanger human health. Member states are required to set standards for these parameters based on the directive, and to monitor the quality of drinking water against those standards. This sub-chapter provides an overview on water related infections and the techniques to measure microbiological quality of drinking water. It also outlines the challenges Kazakhstan is facing in order to meet the standards.

Water related infections and microbial pollution

Microbial contamination of the water environment is associated with a range of human and animal infections caused primarily by pathogenic microorganisms excreted in faeces. These water-related infections can be broadly categorized according to their mode of transmission described for the first time in 1972 in the Bradley classification of water related diseases.

Water-borne: This category includes infections which are caused by the ingestion of infectious agents present in contaminated drinking water causing diarrhoea and other conditions (examples include hepatitis A, polio, cholera, shigellosis, amoebic dysentery, cryptosporidiosis and others). The most common route of transmission is the faecal–oral route. With this route of transmission the infections are often transmitted through contaminated food and lack of hygiene, as well through drinking water.

Water wash/hygiene related: This category includes infections which are effected by the availability, or rather the lack of availability, of water, for washing, bathing and cleaning, leading to poor hygiene. These include skin and eye infections as well as faecal-oral transmission related to a lack of hygiene.

Water based/contact: This category includes infections, which are caused by the infectious agent penetration of the skin on contact with water. These are infections cause by parasitic helminths (worms) whose life cycle includes aquatic intermediate hosts. The most important in this category is schistosomiasis (bilharzia).

Water related vector: This category includes infections transmitted by insect vectors, which breed in water, or bite in the vicinity of water bodies. Infections arising from these vectors include malaria, filariaisis, river blindness (oncocerciasis) and mosquito borne viruses such as yellow fever and Japanese encephalitis. Most are independent of microbiological water quality.

Excreted infections

Microbial contamination of water is associated with a range of human and animal infection, caused primarily by pathogenic microorganisms excreted in faeces, these include enteric viruses, bacteria protozoa and helminths. The route for transport of pathogens to human is shown in figure 1.2.1.

The regular monitoring of water for the presence of a specific pathogen is impracticable and, indeed, unnecessary. Any pathogenic microorganisms present in water will usually be outnumbered by and/or die off more rapidly than normal intestinal flora. The detection of pathogens is, therefore, reserved to specific incidences of pollution and to scientific studies.

A summary of the main commonly excreted pathogens and their associated diseases, classified according to their mode of infection, latency (a dormant period between excretion/exposure and active reinfection/symptoms., persistence (the ability to survive/ subsist in a particular environment) of pathogens in the environment and the infective dose for humans is provided in Table 1.2.1.

Monitoring of microbial quality of water

Monitoring of the microbial quality of water is reliant on relatively rapid, simple tests for the detection of certain commensal intestinal bacteria and related bacteriophages. This is due to their presence in large number in the faeces of man and warm blooded animals and, hence, in sewage.

The criteria for good microbial faecal indicators are that:

- they should be abundant in faeces;
- they should be absent, or present only in small numbers, in the environment;
- their persistence in the environment is equal to, or better than that of, the pathogens;
- their resistance to disinfection is also equal to, or better than that of, pathogens;
- they do not multiply in the environment;
- they are easy to isolate, identify and quantify;
- they are randomly distributed in the sample to be tested; and

- their growth in artificial media is largely independent of other organisms present.

Main indicator groups

- Faecal coliforms have been the main indicators of faecal pollution for over 60 years. These organisms are usually thought of as lactose-fermenting saprophytes. Of this group of bacteria, E. coli, a gram negative rod shape bacterium, belonging to the family Enterobacteriaceae, is the most numerous in human and warm blooded animal intestines. Concentrations reach 109/g in faeces, 106 - 107/100 ml of sewage, and 103 - 106/100 ml in polluted water.

- Faecal streptococci are gram-positive cocci which form pairs or chains and possess Lancefield's Group D antigen. They include a number of different species which occur in man and animal. Concentrations of these reach 106/g in faeces, 106/100 ml of sewage and 103 - 105 /100 ml in polluted water. Faecal streptococci do not multiply in the environment.

- Clostridium perfringens, an anaerobic sulphite-reducing spore forming bacterium, is present in normal faeces in lower numbers than E. coli and faecal streptococci, normally less than 104/g. It is, therefore, less sensitive as a direct indicator, but it is useful in the assessment of the age of the pollution and the effectiveness of water treatment.

- Bacteriophages, somatic and F-specific, specifically those containing RNA (for example, FRNA coliphages), have been proposed as faecal indicators in water. F-specific coliphages infect via the sex (F) pilus of male E. coli strains where pili are made only by cells grown at higher temperatures. They are, therefore, compatible with thermo-tolerant intestinal organisms. FRNA coliphages may also be good surrogates for human enteric viruses such as enteroviruses due to their similarities in structure, nucleic acid, and responses to a variety of water treatment processes.

Other groups of bacteria can be used as indicators for incomplete drinking water treatment or faulty distribution systems, including human pathogens such as Pseudomonas and the Aeromonas groups. These bacteria are naturally present in raw waters and their presence in treated water indicates a breakdown in the treatment or distribution systems. Routine examination of water for these groups is not recommended and is normally only required in the pharmaceutical and food industries and in hospitals.

Common detection and enumeration methods

The methods developed for the detection of faecal microbial indicators in water rely on the use of selective and differential media for their growth. The media contain selective elements, such as bile salts to select for faecal organisms in general and azide to select for faecal streptococci in particular.

Multiple tube test or most probable number (MPN) test

In this method – also known as the dilution test – groups of tubes or bottles (usually five in a group), containing liquid differential medium, are inoculated with specific volumes of a water sample (or sample dilution). Characteristic growth (in the case of coliforms, the production of acid or gas) will happen in a proportion of tubes in each group receiving one or more organisms. The proportions of positive tubes in the various groups receiving different volumes or dilutions can be used to calculate microbial concentration by reference to probability tables.

Membrane filtration test

In this method, a known volume of sample or sample dilution is filtered through a cellulose acetate membrane with a pore size of less than 0.5 microns in order to capture most bacteria. The membrane is then placed on a pad soaked with an appropriate liquid medium, or on agar medium, and incubated under the required conditions. Only colonies which show the sought characteristics are counted.

These two methods have been established and used in the water industry for many years.

Table 1.2.1 Environmental classification of excreted infections – adapted from Feachem et al., 1983

Category and epidemiological features		Infection	Transmission focus	Major control measures
1.	Non-latent; Low infective dose	Amebiasis; Balantidiasis; Enterobiasis; Enteroviral infections [a]; Giardiasis Hymenolepiasis; Infectious hepatitis; Rotavirus infection	Personal; Domestic	Domestic water supply; Health education; Improved housing; Provision of toilets
2.	Non-latent; Medium or high infective dose; Moderately persistent; Able to multiply	*Campylobacter* infection; Cholera; Pathogenic *Escherichia coli* infection [b]; Shigellosis; Salmonellosis; Typhoid; Yersiniosis	Personal; Domestic; Water; Crops	Domestic water supply; Health education; Improved housing; Provision of toilets; Treatment of excreta prior to discharge or reuse
3.	Latent; Persistent; No intermediate host	Ascariasis; Hookworm infection [c]; Strongyloidiasis; Trichuriasis	Farmyards; Fields; Crops	Provision of toilets; Treatment of excreta prior to land application
4.	Latent; Persistent; Cow or pig as intermediate host	Taeniasis	Farmyards; Fields; Fodder	Provision of toilets; Treatment of excreta prior to land application Cooking; meat inspection
5	Latent; Persistent; Aquatic intermediate host(s)	Clonorchiasis; Diphyllobothriasis; Fascioliasis; Fasciolopsiasis; Gastrodiscoidiasis; Heterophyiasis; Metagonimiasis; Opisthorchiasis; Paragonimiasis; Schistosomiasis	Water	Provision of toilets; Treatment of excreta prior to discharge; Control of animal reservoirs; Control of intermediate hosts; Cooking of water, plants and fish; reducing water contact
6.	Spread by excreta-related insects. All the infections in this category are able to be transmitted mechanically by flies and cockroaches	Bancroftian filariasis (transmitted by *Culex pipiens*)	Various faecally contaminated sites in which insects breed	Identification and elimination of suitable insect breeding sites

a. Includes polio-, echo-, and coxsackievirus infections
b. Includes enterotoxigenic, enteroinvasive, and enteropathogenic *E. coli* infections
c. *Ancylostoma duodenale* and *Necator americanus.*

Membrane filtration has the advantage of being easier to perform and results for presumptive counts of coliforms and E. coli are available within 18 hours. It also enables the testing of large volume samples with a low microbial concentration. However, in this case, high levels of non indicator organisms may interfere with the test. In addition, there is no gas production indication, as in the MPN method, and the membrane may get blocked by turbid water. Turbidity may also cause the accumulation of substances inhibitory to indicator growth. In general, then, the MPN method is more suitable for highly turbid samples or for the detection of microorganisms which will not grow on solid medium.

Presence-absence test

This test is based on the principle of the multiple tube method and involves inoculating a double strength differential medium with an equal volume of sample. A positive result obtained from a test of treated water and confirmed by other methods would initiate immediate action.

Microbial quality of drinking water in Kazakhstan

EU member states are required to set standards for drinking water based on The Drinking Water Directive (80/778/EEC) and its revision (98/83/EC). In 2002, Kazakhstan introduced sanitary rules and norm (SanPiN) for drinking water, stating:

- Water conforms to chemical and bacteriological requirements and originates from uncontaminated sources
- The water source is located within the radius of 1 km from the water user's house
- The source supplies 20 L of water per person per day

Water quality for water of household and drinking and those delivered by water trucks is also described in "Sanitary-Epidemiological Requirements of Water Quality of Centralised Drinking Water Supply System" cited in Jumagulov et al (2009).

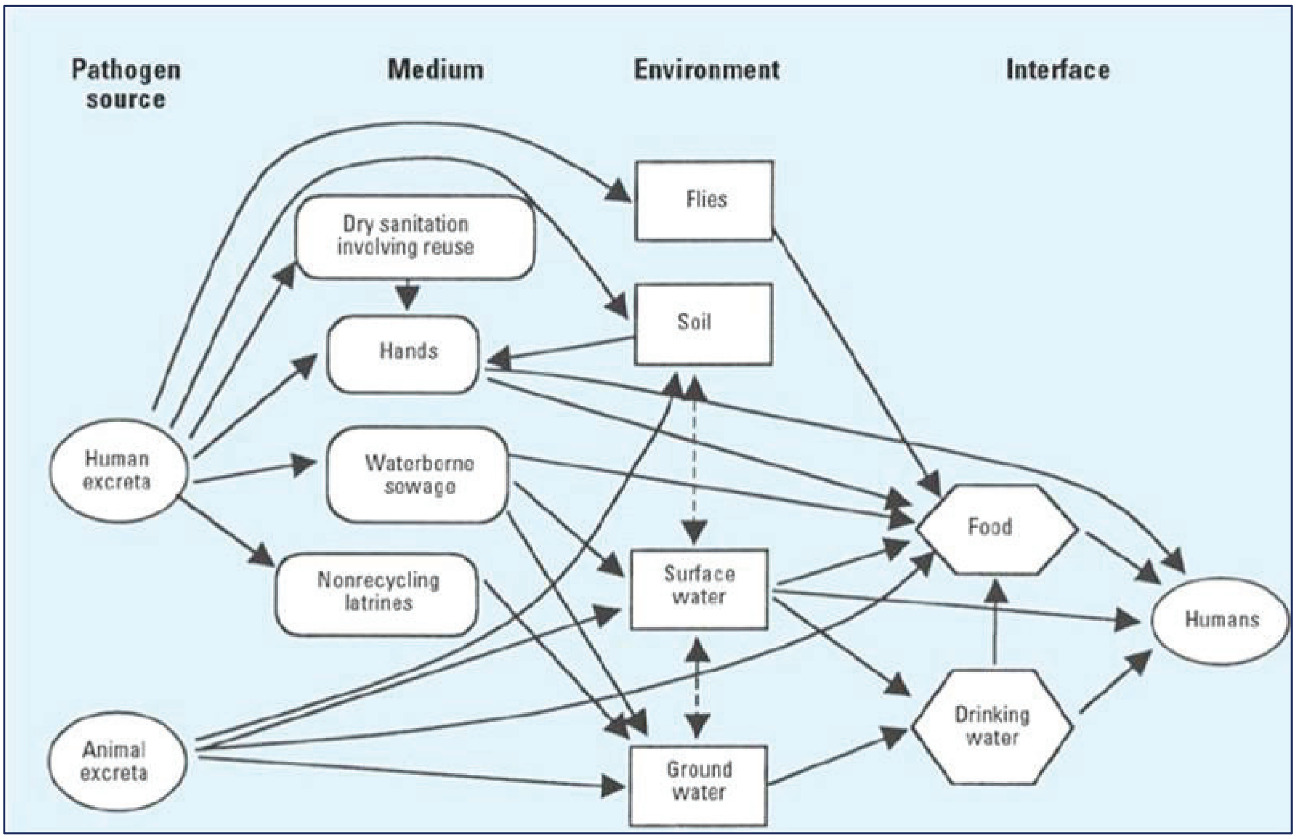


Figure 1.2.1 The faecal-oral route of transmission

The water quality classes based on microbiological parameters are listed in Table 1.2.2. This index is the number of microbial colonies grown in 1 ml of sampled water on a standard meat-peptone agar (MPA). Such a nutrient medium enables the growth of saprophytic bacteria. The ratio of the total number of bacteria on membrane filters to the number of MPA bacteria is used as an indicator of the ecological and microbiological state of water bodies (Abakumov and Talayeva, 1998), even though the clinical and epidemiological evidence that heterotrophic (saprophytic) bacteria pose a health risk is lacking (Riley et al. 2011).

Whilst legislation is in place to safeguard the quality of the drinking water, Kazakhstan faces challenges from aging infrastructure – only about two-third of the population have access to 'improved/safe' water supply sources that do not require urgent repair (Committee for Water Resources, 2006); high cost of chlorination or the use of other disinfectants to minimise microbial contamination; poor sanitary conditions in the water supply system and the use of inferior quality water from natural reservoirs have the potential to give rise to epidemics. Unsafe drinking water is a major cause of diarrhoeal death and disease, especially for young children in low-income settings. Consequently, accurate data on microbial water quality is essential for guiding activities such as water system management and public health campaigns (Peletz et al., 2013). Water quality data is also important for evaluating the effects of water sanitation and hygiene interventions.

Access to water in home also added to the problem. Approx 32% of the survey population in rural area do not have running water (McGee et al., 2006); about 25% of the population do not have access to proper sewage system (UNDP 2013). In many villages, water is obtained from shallow wells. It is also unusual for the walls of these wells to be sealed above the surface to prevent pollution from the surface (Nurgalieva et al., 2002). Whilst one of the United National Development Programme (UNDP) Millennium Development Goals is to halve, by 2015, the proportion of people without sustainable access to clean drinking water and main sanitary technical facilities, research showed that between 2001 and 2010 there was no significant increase access to piped water in urban and rural area in Kazakhstan (Roberts et al., 2012). In Kazakhstan, the morbidity and mortality associated with complications of gastrointestinal diseases is high, with gastric cancer being the second leading cause of cancer death. Helicobacter pylori has been etiologically associated with gastric cancer (Shiotani et al., 2000). The prevalence of H. pylori infection is very high. The data suggest that transmission of H. pylori can be waterborne, related to poor sanitary practices or both (Nurgalieva et al., 2002). Reducing the rate of H. pylori transmission will require improvements in overall sanitation including clean water, waste disposal, as well as in house-hold hygienic practices (Nurgalieva et al. 2002).

Table 1.2.2 Water quality classes in Kazakhstan

Microbiological parameters			
Water quality classes	Total number of bacteria 10^6 cfu/ml	Number of saprophytic bacteria, 1000 cfu/ml	Ratio of total number of bacteria by the number of saprophytic bacteria
I (Very clean)	<0.5	<0.1	>1000
II (Clean)	0.6-1.0	0.1-5.0	100-1000
III (Moderately polluted)	1.1-3.0	5.1-10.0	>100
IV (Polluted)	3.1-5.0	10.1-50.0	>100
V (Dirty)	5.1-10.0	50.1-100.0	100
VI (Very dirty)	>10	>100	<100

To improve the microbial quality of drinking water, it clearly requires long term strategic goal that adopts an integrated approach by the national and regional authorities to promote environmental, social and economic investment and development. The following areas will be crucial to ensure the safety standard for drinking water:

- Improve water supply and access to a reliable supply of water;
- Upgrade existing water treatment;
- Invest on infrastructure to reduce distance to source;
- Establish effective systems of monitoring and surveillance of microbial contamination.

1.3 Urban water supply

Miguel Martin and Enrique Lapuente

E-mail address: mmartin@hma.upv.es

Introduction

Safe water supply is a human right recognized by the United Nations General Assembly (2010). The vital minimum requirement is 15 - 20 litres/person/day. However, even in this case the risk to health due to lack of hygiene, is high. The optimal water supply is 100 litres/person/day and this should be the minimum value utilised in the design of any drinking supply system. Urban water use includes meeting household demands, commercial activities requirements and other uses related to the urban environment such as the cleaning of streets, irrigation of parks and gardens, ornamental fountains, etc.

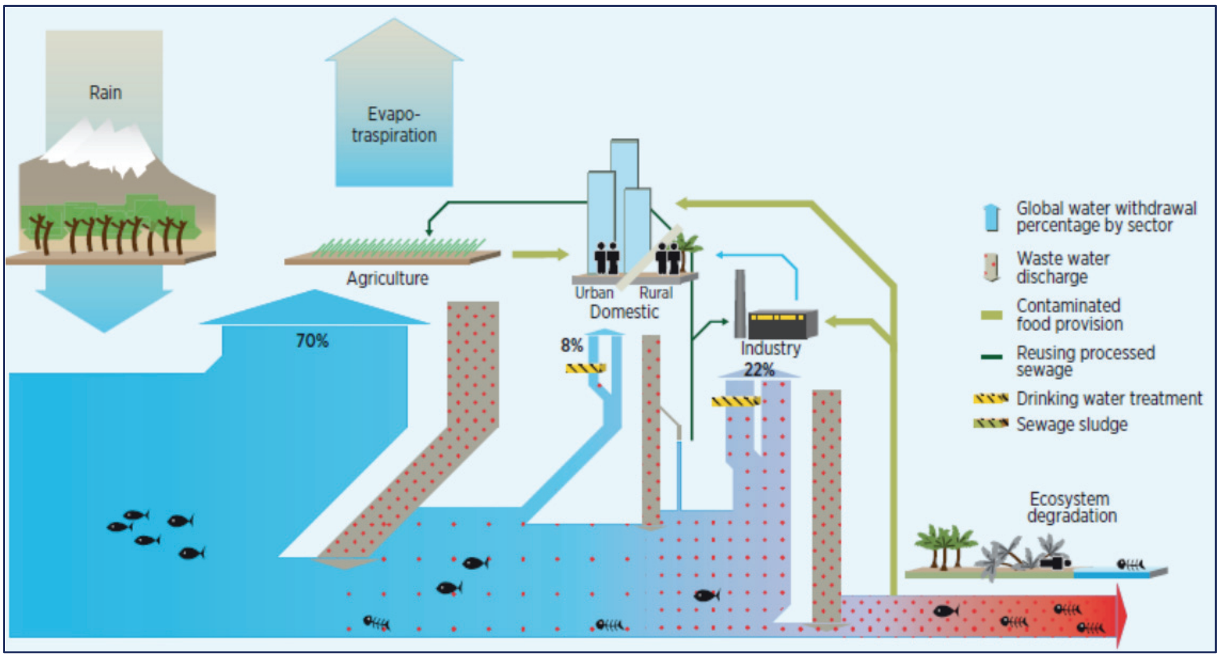


Figure 1.3.1 Urban freshwater and wastewater cycle: Water withdrawal and pollutant discharge. Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/freshwater-and-wastewater-cycle-water-withdrawal-and-pollutant-discharge, by UNEP/GRID-Arendal with sources WHO, FAO, UNESCO and IWMI)

Sources of water supply

In the first instance, the quality of water supplied to a population depends on its source. Conventional water resources come from surface waters (e.g. rivers, lakes, reservoirs) and / or groundwater. While surface waters have historically been the primary source of waters for human beings, groundwater abstractions for water supply has suffered a "boom" during the twentieth century and now supplies nearly half of all drinking water in the world (UNESCO, 2012). In addition to the conventional sources identified, there are non-conventional sources that are used in some urban services:

- Desalination of sea water, brackish/saline water.
- Reuse of treated wastewater (reclaimed water).
- Rainwater harvesting.

The protection of water resources to ensure their long-term sustainability is therefore a primary objective in any water drinking management strategy. A reduction in water quality can occur either by a contribution of pollutants from point or diffuse sources or by overexploitation of available water resources. Both aspects must be appropriately considered in the proper management of water supplies. Worldwide there are several examples of where key aquifers have been contaminated by pesticides, toxic organic compounds, metals (arsenic in Bangladesh and India), nitrates (UE countries: France, Spain) coming from diffuse sources and saltwater intrusion (large cities such Chennai, Jakarta, Lima and Tel Aviv are suffering this problem).

Key water quality parameters

Once abstracted, the water must be properly treated, ensuring its quality to the point of consumption. Potential contaminants are very diverse and include: pathogenic microorganisms, heavy metals, pesticides, dissolved solids, etc. The main pollutants to be controlled in the water supply are (WHO, 2008):

- Microbiological parameters: *Enterococci*, *Escherichia Coli (E. Coli)*, protozoan as *Giardia*, *Cryptosporidium*, etc.
- Chemical parameters: organics (e.g. benzene, 1,2-dichloroethane, trihalomethanes); inorganics (e.g. heavy metals, nitrates, nitrite)
- Indicator parameters: colour, odour, turbidity, oxidisability, etc.

.

Table 1.3.1 (a-d). Parameters and standards in drinking waters for EU countries (CD 98/83/EC), based on the World Health Organisation's 'Guidelines for drinking water quality'

a) Microbiological parameters

Parameter	Parametric value (number/100 ml)
Escherichia coli (E. coli)	0
Enterococci	0

b) Chemical parameters

Parameter	Parametric value - unit
Acrylamide	0,10 μg/l
Antimony	5,0 μg/l
Arsenic	10 μg/l
Benzene	1,0 μg/l
Benzo(a)pyrene	0,010 μg/l
Boron	1,0 mg/l
Bromate	10 μg/l
Cadmium	5,0 μg/l
Chromium	50 μg/l
Copper	2,0 mg/l
Cyanide	50 μg/l
1,2-dichloroethane	3,0 μg/l
Epichlorohydrin	0,10 μg/l
Fluoride	1,5 mg/l
Lead	10 μg/l
Mercury	1,0 μg/l
Nickel	20 μg/l
Nitrate	50 mg/l
Nitrite	0,50 mg/l
Pesticides	0,10 μg/l
Pesticides	0,50 μg/l
Polycyclic aromatic hydrocarbons	0,10 μg/l (Sum of concentrations of specified compounds)
Selenium	10 μg/l
Tetrachloroethene and Trichloroethene	10 μg/l (sum of concentrations of specified parameters)
Trihalomethanes - Total	100 μg/l (sum of concentrations of specified compounds)
Vinyl chloride	0,50 μg/l

c) Indicator parameters

Parameter	Parametric value - unit
Aluminium	200 μg/l
Ammonium	0,50 mg/l=
Chloride	250 mg/l
Clostridium perfringens (including spores)	0 number/100 ml Note 2
Colour	Acceptable to consumers and no abnormal change
Conductivity	2 500 μS cm-1 at 20 °C
Hydrogen ion concentration	6,5 - 9,5 pH units
Iron	200 μg/l
Manganese	50 μg/l
Odour	Acceptable to consumers and no abnormal change
Oxidisability	5,0 mg/l O2
Sulphate	250 mg/l
Sodium	200 mg/l
Taste	Acceptable to consumers and no abnormal change
Colony count 22°	No abnormal change
Coliform bacteria	0 number/100 ml
Total organic carbon (TOC)	No abnormal change
Turbidity	Acceptable to consumers and no abnormal change

d) Radioactivity

Parameter	Parametric value - unit
Tritium	100 Bq/l
Total indicative dose	0,10 mSv/year

Water quality treatment

In some cases, simple physico-chemical treatments, such as filtration, coagulation-floculation and sedimentation, may be sufficient to obtain water quality of the required standard, but the complexity of treatment required on a case-by-case basis ultimately depends on the quality of the source. The last treatment step is disinfection of the water, which is necessary to reduce the risk of waterborne diseases associated with pathogenic microorganisms. The most utilised disinfectant agent world-wide is chlorine, and the disinfection management strategy must ensure a concentration of residual chlorine between 0.5 and 1 mg/l at the user's distribution point (e.g. at point of tap) to prevent pollution in the water supply network. However, it should be kept in mind that chlorinated drinking water processes can produce disinfection by-products (DBPs), such as chloroform ($CHCl_3$), although it is assumed that the health risks due to DBPs are lower than those derived from poor disinfection. In addition to sanitary constraints, the quality of the water should such that the growth of microorganisms (biofilms), corrosion of pipes or solids deposits does not occur into the water distribution system. Finally, seawater and brackish waters require more specific treatment. The use of evaporative systems or reverse osmosis produces water of the required quality but at a significant energy cost. Indeed, the energy footprint of supplying water at the required standard is another key aspect to be considered when developing a water supply strategy. The energy consumption per cubic meter of water treated and supplied varies from 0.05 - 5 kWh where this extended range reflects variabilities in, for example, diversity of origins (e.g. surface, ground, marine desalinated) and the time to transport from origin to the treatment plant.

Once obtained the quality required to be distributed, its transport to the point of consumption should take into account other environmental aspects:

- The minimization of energy consumption (pumping).
- Water losses in the pipes.
- Water pollution due to deficiencies in the network.

Of particular concern are the losses of water from pipes. The ratio between water supplied and lost is site specific because it depends on pressure, soil conditions, corrosion effects, size and material of pipes, temperature variations and the quality of inspection and testing during construction. In some urban settlements the ratio can be higher than 30%. In facing a future scenario of changing climatic conditions with subsequent impacts on water resources it is imperative to work on improvement of the distribution efficiencies of water supply networks. Nowadays, there are several software tools that can help the study of the design of water supply networks. One of the most extended is the public domain software EPANET, from US Environmental Protection Agency.

Water reuse

Current trends, mainly in arid and semi-arid areas, focus on opportunities for the reuse of the wastewaters generated in homes. For instance, in the domestic field there is a tendency towards increasing the grey water recycling rates: i.e. the reuse of waters from baths, showers and wash-hands basins. With a simple treatment system consisting of a sand (or equivalent material) filter and an oxidation/disinfection (with ozone, for example), greywater can be treated and safely used in toilet flushing, for instance. On larger scales, the reuse of treated wastewater from Waste Water Treatment Plants (WWTPs) in aquifers recharge or to directly use in drinking water supply is a way to increase the types of resources used in meeting water supply demands. In the urban environment, the reuse of urban storm waters both for non potable or potable purposes is a cost promising water supply alternative.

Conclusion

Water is the main challenge in the world of XXI Century. To provide safe water to a growing population in more and more growing cities, improving efficiency is a key objective for governments. Once exhausted the conventional sources of water, non conventional sources must be increased but simultaneously improving the renewable sources of energy.

1.4 Urban wastewater

Miguel Martin and Enrique Lapuente

E-mail address: mmartin@hma.upv.es

Introduction

Urban wastewaters are defined as the wastewater coming from housing and associated services, generated as a result of the human metabolism and domestic activities e.g. bathing and cooking. Depending on the activities undertaken in the area, industrial wastewater or urban stormwater runoff may also contribute to urban wastewater flows (Directive 91/271/EEC). The human use of water resources significantly impairs their quality by introducing therein new substances and/or increasing the concentration of some which occur naturally. The main substances that are of concern are:

- Oils and fats.
- Total solids (TS): the sum of dissolved solids (TDS) and total suspended solids (TSS).
- Organic matter.
- Pathogenic micro-organisms.
- Nutrients: ammonia, nitrates, phosphates.
- Dissolved salts.
- Heavy metals.
- Organic toxics: pesticides, solvents.

Many of these substances are assimilated by aquatic ecosystems, given its organic origin, but the magnitude of their discharge into the environment may exceed the natural treatment capacity. In many cases throughout the world, point discharges have caused problems such as depletion of dissolved oxygen levels, eutrophication, transmission of disease, etc., preventing the further use of the waters. In recent years, emerging pollutants of concern include pharmaceutical products, cosmetics, etc., whose environmental effects are beginning to be known.

Key wastewater treatment system design parameters

The most common method for estimating the biodegradable organic matter loading within a wastewater sample involves determining its biochemical oxygen demand over a period of five days (BOD_5). This test involves determining the oxygen consumed in that period of time by heterotrophic aerobic bacteria as they degrade organic matter. An important concept in the design of sanitation facilities is the population equivalent (Pe): a figure which represents an organic load of 60 g BOD_5 per inhabitant per day. 'Pe' is a useful planning concept commonly used in the sewage treatment facilities design process. In brief, it enables the size of the population to be translated into an equivalent organic loading value, the magnitude of which is then used to inform the treatment capacity of the plant. Urban waste-water management covers the following aspects:

Table 1.4.1 Typical values of untreated wastewater (Metcalf & Eddy, 2013) and requierements for discharges from WWTP in UE. The ranges of wastewater concentrations depend on water dilution and the addition of organic wastes others than faecal

Water quality variable	Wastewater concentration			Requirements for discharges from WWTP (EC Directive 91/271)
	Strong	Medium	Weak	
Total solids (mg/L)	1200	720	350	
Total dissolved solids (mg/L)	850	500	250	
Total suspended solids (mg/L)	350	220	100	< 35
BOD_5 (mg/L)	400	220	110	< 25
COD (mg/L)	1000	500	250	< 125
Total nitrogen (mg N/L)	85	40	20	To sensitive areas subjected to eutrophication < 15 (10000 - 100000 p.e.) < 10 (more than 100000 p.e.)
Organic nitrogen (mg N/L)	35	15	8	
Ammonia (mg N/L)	50	25	12	
Nitrates (mg N/L)	0	0	0	
Total phosphorus (mg P/L)	15	8	4	To sensitive areas subjected to eutrophication < 2 (10000 - 100000 p.e.) < 1 (more than 100000 p.e.)
Organic phosphorus (mg P/L)	5	3	1	
Inorganic phosphorus (mg P/L)	10	5	3	
Total Coliform (MPN/100 mL)		10^8		
Faecal Coliform (NMP/100 mL)		10^7		

- Design and management of sewerage systems.
- Design and management of treatment systems.
- Management of the treated water.
- Management of generated sludge.

The flow volume of generated wastewater is a further key aspect in the design of sewage collection systems and treatment plants. In relation to the flow volume it is essential to determine in each case:

- Average daily flow (including its variation depending on the day of the week and season)
- Peak flows: on hourly, daily and monthly bases.

There are empirical relationships between mean daily flow and the peak flow. Usually, the relationship between the peak flow and average flow is between 1.3 and 2.0. This value is greater the smaller the size of the city, and can be estimated using the following relationship:

$$PDWF = ADWF\left(1.15 + \frac{2.575}{ADWF^{1/4}}\right) \quad \left(m^3/h\right)$$

Where:
PDWF: Peak dry weather flow volume (m^3/h).
ADWF: Average dry weather flow volume (m^3/h).

Flow volumes can be calculated from field studies, estimated as a percentage of the urban supply or assuming a specific endowment per capita and day. This amount depends on several factors:

- Urban or rural environment.
- Water resources availability.
- Economic activity.

Considerations in sizing a wastewater treatment plant

Collector system design depends greatly on the study of flow rates. Collecting systems can be combined (i.e. specifically designed to transport both sewage and stormwater runoff), or separate (i.e. foul sewage and surface rainfall runoff carried in separate piped systems). One of the main problems in sewer management is the large flow volumes generated by storm events and how these episodic and sometimes massive flow volumes can be managed. Stormwater may produce hydraulic overloading in WWTPs and, also, changes in wastewater characteristics: the first flush usually increases the pollutant concentrations due to the flushing of the collectors, whereas continuous rain dilutes the pollutant concentrations of wastewaters. Nowadays, the development in urban areas of Sustainable Urban Drainage Systems (SUDS) as green swales, basins retention or vegetated roofs has shown great progress in mitigating sewers overflow.

Among the software tools that can be used to study the hydrological water cycle and the relationship with the wastewater networks, INFOWORKS CS is one of the most interesting. It is ready to solve any hydrological question in the urban catchment and also includes a water quality module. Management and treatment of urban wastewater can be of two main types: centralized in large facilities and sanitation networks or decentralized in small systems. The best solution depends on numerous economic, technical, social and climatic factors. In the context of integrated water resource management, treated wastewaters should be returned to the environment in a condition which does not impair the quality of the receiving waters.

Performance of wastewater treatment systems

The purpose of the treatment of wastewater is the return of water used by a population to the receiving environment in a state where it is able to assimilate the both the quantity and quality of the discharge without an appreciable effect. The most significant effects on aquatic ecosystems are as follows:

- Suspended solids: decrease of the transparency of waters, the adsorption of toxic organic compounds (e.g. heavy metals and organic compounds) by suspended solids and subsequent development of layers of settled sediments with high polluting potential
- Biodegradable organic material, organic nitrogen and ammonia: reduction of dissolved oxygen in the water.
- Inorganic nitrogen and inorganic phosphorus: promotion of algae growth, risks of eutrophication.
- Pathogenic microorganisms: risk of transmission of diseases

The most commonly utilised process in wastewater treatment for centralized facilities is the biological process "activated sludge treatment" (see section 4.4). In rural areas, low cost technologies with low energy requirements are developed according to climate conditions and land availability; tricking filters and constructed wetlands are two interesting examples of such biological treatment facilities. Prior to any biological treatment (also named "secondary treatment"), the use of a "primary treatment" is mandatory to reduce total suspended solids. The main residual of a wastewater treatment plant is the sludge, a mixture of water, bacteria, other organics and inorganic suspended solids that must be properly disposed. For example, it could be used as fertilizer after digestion (aerobic or anaerobic) and composting. The amount of dry sludge produced ranges from 35 to 85 g/p.e.day. The "sludge line" the set of unit operations implemented in a WWTP needed to reduce its volume and sanitary/environmental risks, is almost as important as the water treatment.

In some countries regulations are based on fixing a limit to the discharge of these pollutants from the wastewater treatment plant to the receiving waters; in others, the limit is the total daily load based on the assimilative capacity of the receiving environment. In both cases, the development of water quality models (WQMs, based in advective-diffusive transport and source/sink terms) is a valuable tool to study the environmental impact and consequently to assess in each case the maximum pollutant load which can be discharged by a WWTP. Nowadays, a very long list of WQMs software is available worldwide. In Europe, DELFT3D (Deltares, Netherlands) and MIKE by Danish Hydraulic Institute are among the most recognized commercial software, whereas MOHID (Maretec, Portugal) is a robust software available on the internet. In the United States both

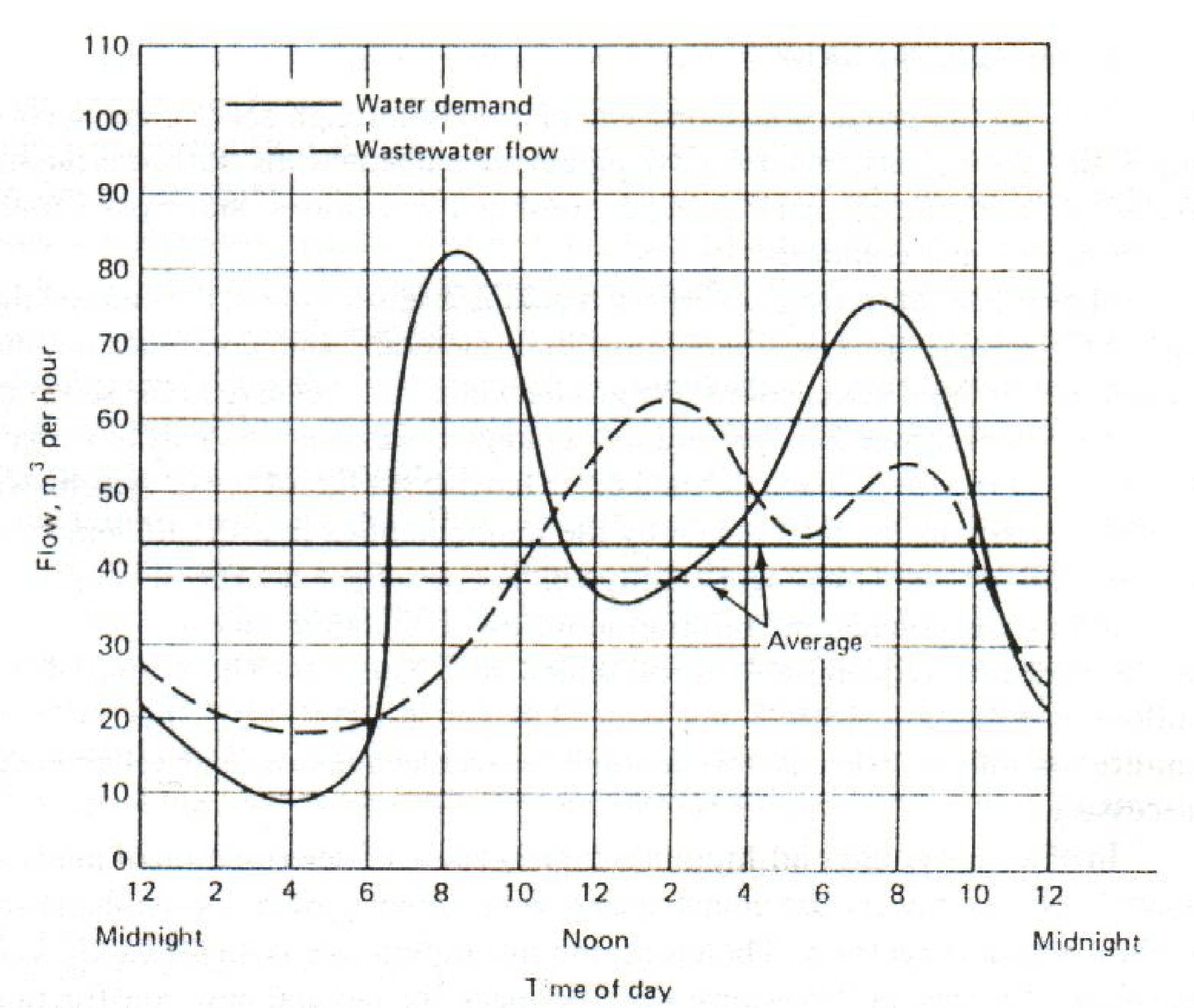


Figure 1.4.1 Typical daily profile of water demand and wastewater flow in cities higher than 50000 pe

available on the internet. In the United States both the Geological Survey (USGS) as the Environmental Protection Agency (USEPA) have been developed environmental software since the 1960's which are freely distributed: two examples of successful WQMs are QUAL2E and WASP7. All of them solve the mass balance equation for any concerning water quality variable: since simple BOD-OD interactions to more complex eutrophication problems in one, two or three dimensions. At last, a very useful tool for modellers is AQUASIM, a software framework that allows you to build your own WQM. .

Conclusion

The management of urban wastewater must be integrated in a joint management plan including drinking water, rainwater and wastewater in the urban environment. New city developments must take into account the frequently overloaded facilities and thus develop more sustainable alternatives. In arid climates, current trends are towards the maximum, direct or indirect, reuse of treated waters. In this respect it should be borne in mind that the use of drinking water increases water salinity, and that these salts are not eliminated in the conventional wastewater treatment plants.

1.5 Urban stormwater Best Management Practices

Lian Lundy

E-mail: L.Lundy@mdx.ac.uk

Introduction

This sub-chapter introduces the concept of the water cycle and describes how urbanisation impacts on its functioning, with a particular focus on its implications for the management of rainfall volume and quality in urban areas. The conventional approach to managing rainfall (or urban stormwater) is briefly reviewed within the context of integrated water cycle management (IWCM) needs. An alternative approach to managing urban stormwater flows – the use of stormwater best management practices – is presented and described. Opportunities for stormwater to be valued as a resource (as opposed to a wastewater type) are highlighted.

The impact of urbanisation on the water cycle

The hydrological or water cycle refers to the continuous movement of water from the earth's atmosphere on to land or water bodies and back up to the atmosphere. Key processes in this cycling of water are identified in Figure 1.5.1.

In urban areas, the construction of roads, pavements and buildings all result in the land on which construction takes place becoming increasingly impermeable. As urban areas expand and develop, the amount of land covered in impermeable materials (e.g. tarmac, brick and concrete) also becomes greater and greater. Hence urbanisation effectively results in the sealing of surfaces so that any rainfall received cannot penetrate into the ground. This seriously impacts on the natural functioning of the water cycle, with associated implications for IWCM as summarised in Table 1.5.1.

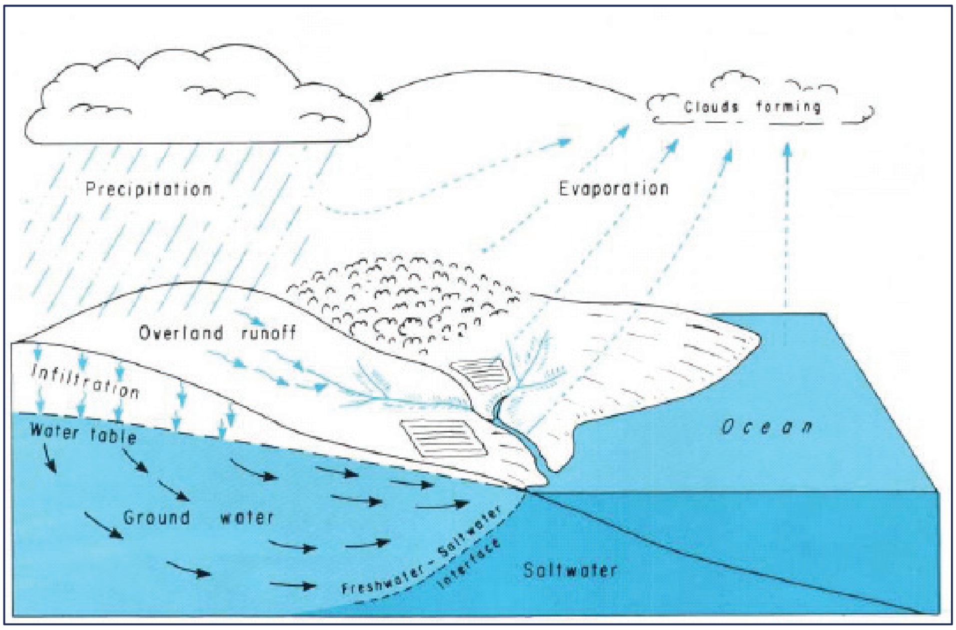


Figure 1.5.1 Key processes involved in the water cycle (Heath, 2004)

Of the 7.2 billion people on earth, just over 50% are reported to live in urban areas, with the urban population predicted to increase by a further 2.4 billion by 2050 (UN, 2012). This continued and rapid growth of urban areas throughout the world places ever greater pressures on the functioning of the water cycle in meeting needs for water supply (for both drinking and irrigation), sanitation and stormwater management.

Table 1.5.1 Key impacts of urbanisation on the functioning of the water cycle

Process affected	Type of impact	Implications for IWCM
Infiltration	Surface sealing reduces volume of water that can infiltrate into the ground.	Diminishing water levels in groundwater and surface water bodies
Surface runoff	Surface sealing increases the volumes of surface runoff generated.	Large volume of water generated quickly; implications for flood management.
Groundwater recharge	Decreased infiltration leading to decreased groundwater levels	Subsidence of land/buildings; diminished drinking water supplies
Surface water recharge	Decreased inter-flow between groundwater and surface water bodies	Reduced flows/water levels in rivers and lakes etc; implications for drinking water supply and receiving water ecology
Transpiration	Urbanisation reduces the amount of vegetation/green space, reducing associated levels of transpiration	Reduced level of transpiration contributes to increasing surface water flows

The traditional approach to managing urban stormwater runoff and why a change is needed

As noted in Table 1.5.1, the increase in impermeable surfaces characteristically associated with urban development means that, depending on site specific characteristics, even minor rainfall events can result in the generation of large volumes of surface water. The traditional approach to managing urban stormwater flows involves directly draining stormwater via wastewater pipes to the nearest wastewater treatment plant to meet the key drivers of avoiding localised flooding and potential risks to human health from waterborne diseases.

The piped approach to managing urban stormwater flows was developed at a time when sustainability criteria were not of major relevance, or, in many cases, even a consideration. However, views on such hard engineering approaches started to shift in the latter part of the last century as it began to be recognised that the piped approach simply moved stormwater flows (or 'the problem') from one location to another, rather than managing 'the problem'. As urban areas progressively expanded, the associated increasing levels of impermeability meant that the same sized rainfall events were generating ever great volumes of surface runoff to the extent that wastewater treatment plants could no longer cope with the volumes of waters been generated. To avoid flooding on land, two approaches were put into place:

- Installation of combined sewer overflow pipes; effectively by-pass pipes that discharged a combination of raw seage and rainfall into receiving waters
- Separate surface water piped systems which directly drain surface water flows to the nearest water course.

However, cities continued to expand and as a result combined sewer overflow pipes that were anticipated to discharge once or twice a year, now discharge on a weekly basis. For example, in London (UK), combined sewer overflows that were designed in the 1800s to discharge once or twice a year into the River Thames now discharge on average once or twice a week resulting in an estimated 39 million cubic metres of untreated sewage entering the Thames in an average year (Thomas and Crawford, 2010). A further concern is that these issues are apparent under current climatic conditions, with impacts predicted to exacerbate under future climate predictions which suggest changing rainfall patterns are likely to include intense episodic rainfall events with high runoff amounts (IPCC, 2007).

The second approach (separate surface water piped systems) is also criticised for two reasons. Firstly it was developed at a time when stormwater was considered to be essentially 'clean water' with little, if any potential, to negatively impact on the ecology of receiving water bodies. However, it is now recognised that as stormwater travels over impermeable surfaces it can mobilise and transport pollutants that have been deposited there as a result of processes such as aerial deposition, traffic and industrial activities (Baun et al., 2006). For example, runoff from densely trafficked areas can contain elevated loads of a range of organic and inorganic pollutants, from particulate matter to heavy metals and polyaromatic hydrocarbons at concentrations that can result in the restriction of receiving water flora and fauna to pollution tolerant families (Lundy et al., 2011). The piped approach to managing stormwater flows also results in a large volume of water discharging into a receiving water at a single point, resulting in both bank erosion and flooding both and further downstream. A further key driver for change in Europe is the on-going implementation of the EU WFD, which specifically refers to the need to tackle diffuse pollution (such as urban stormwater runoff) if its stringent requirements for all water bodies to achieve good ecological status are to be achieved (see chapter 2.3 for detailed description of the EU WFD).

In order to meet these changing requirements an alternative approach to use the use of pipes to manage stormwater management is needed. This has led to increasing interest in the use of stormwater best management practices (BMPs). BMPs encompass a wide range of solutions which enables the planning, design and management of stormwater to be tackled from hydrological, environmental and public amenity perspectives (CIRIA, 2001). BMPs can be used as an alternative to, or in combination with, conventional stormwater drainage systems.

Stormwater best management practices (BMPs)

The term stormwater BMP refers to a wide range of systems types which can be categorised into one of four broad (and sometimes overlapping) groupings depending on their 'dominant characteristic' e.g. storage, infiltration etc (see

Table 1.5.2 Descriptions of types of structural BMPs

Structural BMP category	System name	Description
Storage systems	Constructed wetlands	Vegetated system with extended retention time.
	Retention ponds	Contain some water at all times and retains incoming stormwater.
	Detention basins	Dry most of the time and able to store rainwater during wet conditions.
	Sedimentation tank	Concrete structure containing to assist the settling of suspended solids under quiescent conditions.
Conveyance mechanisms	Filter strip	Grassed or vegetated strip of ground that stormwater flows across.
	Swales	Vegetated broad shallow channels for transporting stormwater.
Infiltration systems	Filter drains	Gravelled areas where stormwater can drain through the gravel to be collected in a pipe.
	Soakaways	Chamber or rock-filled volume: stormwater soaks into the ground via the base and sides.
	Infiltration trench	A long thin soakaway.
	Infiltration basin	Detains stormwater above ground which then soaks away into the ground through the base.
Alternative surfacing materials	Porous asphalt	Open graded powdered/crushed stone with binder: high void ratio.
	Porous paving	Continuous surface with high void content, porous blocks or solid blocks with infiltration spaces; associated reservoir structure provides storage.

Table 1.5.2). In contrast to conventional piped systems which only address stormwater management from a water quantity perspective e.g. pipes remove water from the local areas as quickly as possible, structural stormwater BMPs aim to treat stormwater as close as possible to its source, reducing runoff volumes, pollutant loads and flow rates by collecting, temporarily storing and subsequently discharging at a controlled rate to the soil or the downstream receiving watercourse or sewer. However, as well as contributing to flow volume objectives, stormwater BMPs also offer opportunities for pollutant removal (as a function of a range of biological and physico-chemical processes) and can contribute to achieving a range of habitat and amenity objectives.

As can been seen in Figures 1.5.2-5, structural stormwater BMPs come in arange of shapes, compositions and sizes, with each system type differentially contributing to water quantity, quality or amenity objectives.

Figure 1.5.2 Example of a storage BMP: a retention pond (Photo credit: with kind permission of SUDSnet University of Abertay Dundee)

Figure 1.5.3 Example of infiltration BMP: a filter drain(Photo credit: with kind permission of SUDSnet University of Abertay Dundee

Figure 1.5.4 Example of a transfer BMP: a swale (Photo credit: with kind permission of SUDSnet University of Abertay Dundee

Figure 1.5.5 Example of an alternative surfacing material BMP: porous paving (Photo credit: with kind permission of SUDSnet University of Abertay Dundee

For example, depending on its size and design, a constructed wetland can contribute to all three objectives. Both natural and man-made wetlands act as sponges offering considerable potential for storage of stormwater flows. The presence of vegetation slows incoming flows facilitating a range of removal processes such as the settlement of particulate matter and associated pollutants, photolysis and volatilisation (Scholes et al., 2007). Once within the wetland substrates, pollutants may then be subject to a further range of processes such as microbial degradation and plant uptake. Such vegetated systems can also provide valuable habitat for a range of species from fish and birds to insects and amphibians, with associated benefits as sites for recreation e.g. bird watching, walking and the opportunity to spend time in a tranquil location.

Infiltration trenches are essentially gravel filled ditches (see Figure 1.5.3). They are less space demanding than constructed wetlands and can therefore more readily fit into urban areas where land availability can be at a premium. Depending on their size, they can provide storage of stormwater volumes (for subsequent release at a slower rate into soils/receiving waters), their rock infill provides opportunities for particulate removal (via processes such as filtration and adsorption) as well as providing attachment sites for micro-organisms enhancing subsequent opportunities for microbial degradation to occur. However, as largely sub-surface systems, infiltration systems offer limited habitat/amenity opportunities other than that which may be associated with any colonising vegetation.

Transfer BMPs, such as swales (see Figure 1.5.4) and filter strips are again easier to fit into new and existing developments than the larger storage BMPs. These BMPs are often used instead of a pipe to collect stormwater flows from e.g. a length of road and transfer it to for example, a retention basin. As transfer systems, such BMPs offer relatively limited opportunities for flow storage but, as with constructed wetlands, the presence of vegetation facilitates a range of pollutant removal processes from buffering of flow promoting settlement of particulate matter to infiltration into sub-surface soils and subsequent microbial degradation /microbial mediated transformation of pollutants. As vegetated systems, they can contribute valuable green space within otherwise densely urbanised areas contributing although recreational opportunities are limited (if any).
Alternative surface materials can come in a range of forms; from permeable materials (e.g. porous asphalt (surface material only) and porous paving (permeable surface with associated sub-surface storage) to impermeable paving blocks with adjacent infiltration spaces. Depending on the level of associated storage, such BMPs can contribute to water quantity objectives, provide opportunities for pollutant removal (e.g. filtration, adsorption and microbial degradation) but offer little direct contribution to the achievement of any habitat/amenity objectives.

Conclusion

The conventional piped approach to managing urban stormwater flows is no longer considered best practice in relation to economic, social or environmental objectives. In many cities around the world existing piped systems are already at capacity, limiting further urban development opportunities. In simply 'trans-locating' stormwater flows downstream, piped systems effectively manage stormwater flows as a wastewater with little if any value. Our growing cities place increasing demands on the water cycle to meet drinking water, irrigation and sanitation requirements amongst a range of other 'quality of life' needs that water can play a key role in providing. Whilst no easy task (rain often falls in the 'wrong place' and at the 'wrong time'), this inherent ability of cities to generate and collect large volumes of water could and should be viewed as a valuable asset. The use of stormwater BMPs provides opportunities to start to 'turn the tables' on the significant challenge of managing urban stormwater flows through re-establishing functioning of the water cycle in urban areas (through enhancing opportunities for infiltration, groundwater recharge and transpiration to take place), freeing up capacity in sewerage systems thereby enabling further development and providing habitat and opportunities for amenity and relaxation in otherwise frenetic urban living spaces.

1.6 Minimal environmental flows and levels

Burghard C. Meyer

Email address: Burghard.meyer@uni-leipzig.de

Introduction

Water withdrawals for irrigation or other water usages from running waters, standing waters or groundwater are sustainable made and managed only up to a critical quantity (amount, flow, level or threshold) without causing ecological or other damages. Damages can occur on a local site, e.g. by a drying out of a local system, or on regional geographic scale, as the well-known Aral Sea disaster has shown. Water levels and flow thresholds have to be found based on scientific analysis – society and politics will discuss and negotiate the levels for decision making in integrated water cycle management. The management can include transboundary negotiations.

The minimum residual flow or minimum flow is the amount of water, which must at least remain in the waters/rivers/wetlands and aquifers. Ecologically necessary, minimum flows or minimum water levels of running waters, lakes, groundwater or wetlands are essential to avoid the damages (Fig. 1.6.1). The minimal water flow is required to sustain freshwater and estuarine ecosystems and includes the human well-being, the landscape functioning and the ecosystem services (Richter et al. 2006, Davis et al. 2013). It helps to decide ecological key questions about the flow of water within and between different kinds of ecosystems including managed and used

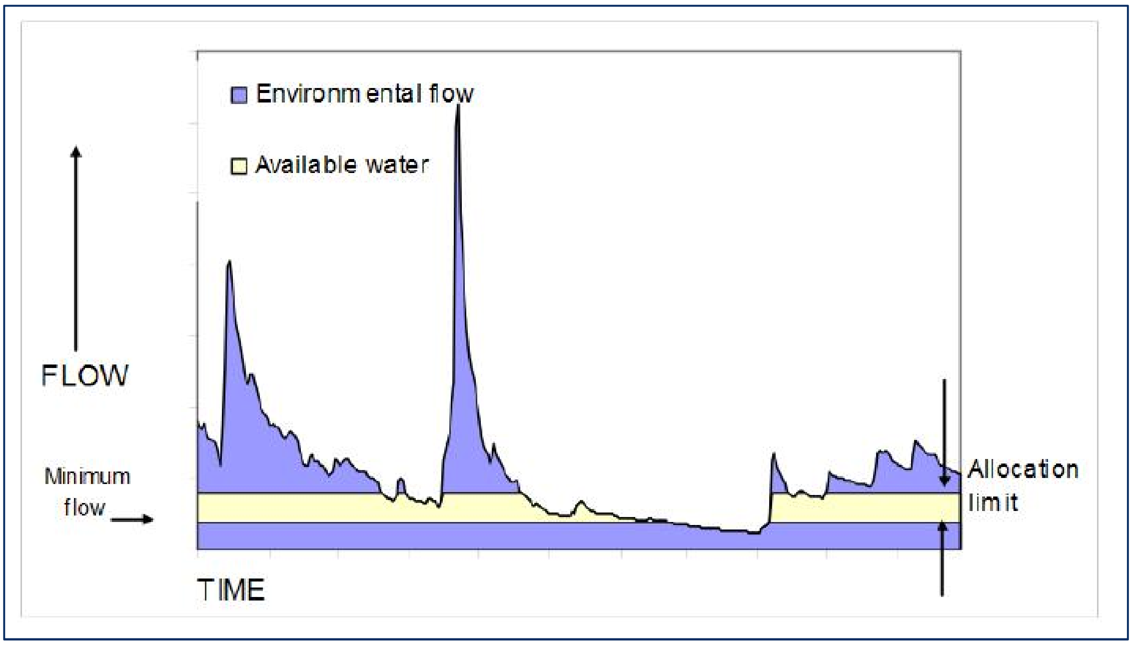


Figure 1.6.1 Simple environmental flow diagramme integrating flow level and time (MfE, 2008)

essential to ensure the ecological functioning, in rivers especially as a habitat for fish and other species (fauna, flora, habitats) and also for other landscape usage related aspects e.g. by a scenic necessary minimum flow in urban for recreational usage (Figure 1.6.2).

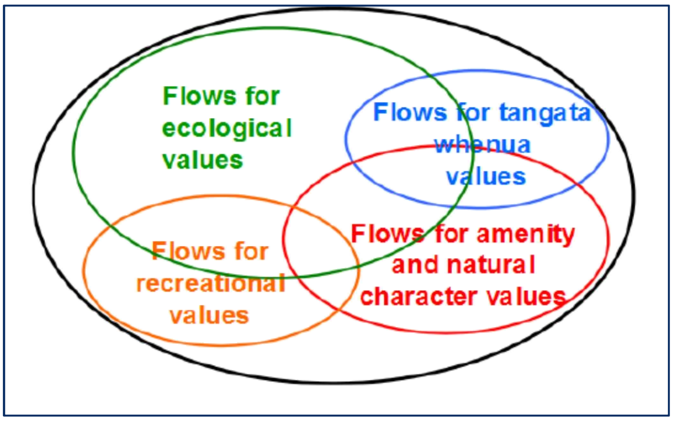


Figure 1.6.2 Components of Environmental flows and water levels for New Zealand (MfE, 2008; tangata whenua values of indigenous people; here the Maori).

The environmental flows approach includes timing, quality, and quantity of water flows ecosystems. Methods to establish ecological flows and water levels for rivers, lakes, wetlands, and groundwater resources have to be developed before scientifically sound advices about critical levels and thresholds can be given. The methods application and a river basin adapted methods development can include simple formula on a local scale up to complex and long-term data based on large-scale model frameworks for the risk approximation at catchment level. Subjects or indicators with influence on threshold formulation are abiotic factors (e.g. flow, light, temperature, chemistry, velocity and substrate), biotic indicators (e.g. fish indicators, connectivity, habitat quality) or societal and economic use factors (e.g. industrial, residential or agricultural water withdrawal, recreation, scenery etc.).

Natural and seasonal dynamics, including climatic fluctuation, have to be known in order to estimate any impact on the water-flow regime. Following Davies et al (2013) subjects of environmental flow analysis include the magnitude, the timing, the duration, the frequency and the knowledge about the rate of change when finally defining threshold levels to differentiate flows into extreme low, low, high, small floods or large floods by using here the impact on a river as example.

Methods for the estimation of minimal water flow for rivers, lakes, wetlands and groundwater

The Ministry for the Environment of New Zealand (MfE; 2008a) has assessed the need for a National Environmental Standard (NES) on methods for establishing ecological flows and water levels for rivers, lakes, wetlands, and groundwater resources. This example gives the scientific basis for further investigations on such type of problems also for the application in Kazakhstan. The MfE (2008a) was interested in developing, with the help of an expert group, "scientific guidelines to select appropriate methods to determine ecological flows and water levels" to "establish ecological flow requirements". A Workshop held in 2006 (1) "listed the ecological management objectives/values relating to the ecological flow/level of the river, lake, wetland or groundwater resource being considered, together with factors that might affect the ability to achieve that objective; (2) listed the technical methods applicable to the setting of ecological flows and water levels for the type of water body under consideration and debated the pros and cons of each method and (3) developed a matrix of methods applicable depending on the significance of the values perceived for the water resource under consideration, and the degree of hydrological alteration being considered for that water resource". The study formulated results for flow analysis in rivers, lakes, wetlands and groundwater.

It includes for rivers (1) "the assessment of risk of deleterious effects on instream habitat according to fish species present and natural mean stream flow"; (2) the "relationship between degree of hydrological alteration and total abstraction expressed as % of mean annual low flow for various risk classifications based on stream size and species composition" and (3) the "methods used in the assessment of ecological flow requirements for degrees of hydrological alteration and significance of instream values" (Table 1.6.1).

The MfA's (2008) study explains that the "degree of hydrological alteration for a river can be expressed first by determining the risk based on mean flow and species present, and second using a combination matrix to determine how the total abstraction in terms of mean annual low flow, (MALF) affects the degree of hydrological alteration for the stream and its risk category and its baseflow characteristics". Recommendations for an appropriate methods selection were also formulated for lakes, wetlands and groundwater (see MfA, 2008a).

Examples for risk formulation of potential changes: The same study developed for the application in New Zealand, proposed also "that for **lakes**, the risks for a potential change to lake level may be defined as follows:
(1) **Low**. Less than 0.5 m change to median lake level in lakes greater than 10 m depth, and less than 10% change in annual lake level fluctuation in lakes greater than 10 m depth; and less than 10% change in median lake level and annual lake level fluctuation in lakes less than 10 m depth; and, patterns of lake level seasonality (relative summer vs winter levels) remain unchanged from the natural state.
(2) **Medium**. Between 0.5 and 1.5 m change to median lake level and less than 20% change in annual lake level fluctuation in lakes greater than 10 m depth; and between 10 and 20% change in median lake level and annual lake level fluctuation in lakes less than 10 m depth; and, patterns of lake level seasonality (relative summer vs winter levels) show a reverse from the natural state.
(3) **High**. Greater than 1.5 m change to median lake level, and greater than 20% change in annual lake level fluctuation in lakes greater than 10 m depth, and more than 20% change in median lake level and annual lake level fluctuation in lakes less than 10 m depth; and, patterns of lake level seasonality (relative summer vs winter levels) show a reverse from the natural state."
For **wetlands** the study proposes the following thresholds on the "potential risk of ecological change associated with changes in levels may be defined as follows:
(1) **Low**. Less than 0.2 m change in median water level; and, patterns of water level seasonality (summer vs. winter levels) remain unchanged from the natural state (summer relative to winter);
(2) **Medium**. Greater than 0.2 m and less than 0.3 m change to median water level; and, patterns of water level seasonality show a reverse from the natural state (summer relative to winter); and
(3) **High**. Greater than 0.3 m change to median water level; and, patterns of water level seasonality show a reverse from the natural state (summer relative to winter)."

Table 1.6.1 Methods used in the assessment of ecological flow requirements for degrees of hydrological alteration and significance of instream values (MfE 2008a) for rivers

Degree of hydrological alteration	Significance of instream values		
	Low	Medium	High
Low	• Historical flow method • Expert panel	• Historical flow method • Expert panel	• Generalised habitat models • 1D hydraulic habitat model • Connectivity/fish passage • Flow duration analysis
Medium	• Historical flow method • Expert panel • Generalised habitat models	• Generalised habitat models • 1D hydraulic habitat model • Connectivity/fish passage	• 1D hydraulic habitat model • 2D hydraulic habitat model • Dissolved oxygen model • Temperature models • Suspended sediment • Fish bioenergetics model • Groundwater model • Seston flux • Connectivity/fish passage • Flow variability analysis
High	• Generalised habitat models • 1D hydraulic habitat model • Connectivity/fish passage • Periphyton biomass model	• Entrainment model • 1D hydraulic habitat model • 2D hydraulic habitat model • Bank stability • Dissolved oxygen model • Temperature models • Suspended sediment • Fish bioenergetics model • Inundation modelling • Groundwater model • Seston flux • Connectivity/fish passage • Periphyton biomass model	• Entrainment model • 1D hydraulic habitat model • 2D hydraulic habitat model • Bank stability • Dissolved oxygen model • Temperature models • Suspended sediment • Fish bioenergetics model • Inundation modelling • Groundwater model • Seston flux • Connectivity/fish passage • Periphyton biomass model • Flow variability analysis

Groundwater: "it is proposed that for groundwater the potential risk for changes in levels may be defined as follows:
(1) **Low**: Less than 10% of average annual recharge;
(2) **Medium:** 11% to 25% of average annual recharge and
(3) **High:** Greater than 26% of average annual recharges"(MfA 2008a).

Conclusion

The example given on the determination of methods to analyse and to predict water flows and levels by using methods applicable for the establishing of ecological flow requirements shows the complexity for a valid investigation on impacts of water uptake from rivers, lakes and groundwater including the impacts on wetlands. Essential is the choice of meaningful indicators and methods to understand the impact of a change in a dynamic hydrological system. Expert panels or decisions without modelling applications are only suitable if the impact is characterised in the low level category of risk. It should be stressed, that not a single impact is normally the subject of an investigation about minimal water levels and flows – the whole catchment system and a multitude of impacts e.g. on the up-, middle- and down-stream region of a river should be focused integrative.

1.7 Soil properties as indicators for degradation processes caused by surface water runoff

Christian Schneider and Ronny Schmidt

Email address: christian.schneider@uni-leipzig.de

Introduction

Soil erosion is strongly connected to surface water runoff. Observations and measurements of water-bound erosion processes are very complex and time consuming. Soil profile analyses provide valuable indicators to reconstruct runoff processes and dynamics. The impact of erosion processes can easily be evaluated by focusing on differences between investigated soil profiles and modelled ones, applying the concepts of chrono- and toposequences. The extent of soil erosion or accumulation is a valuable indicator for the vulnerability of a site, with respect to water-bound erosion. Thus, it is possible to determine vulnerable areas and slope positions with an increased demand for soil protection measures. Most soil protection activities aim at a reduction of runoff by increased infiltration or by modifying surface water dynamics.

Surface runoff and soil erosion

The degradation and destruction of soil is a worldwide problem which might endanger global food production in the future. Physical, chemical and biological processes limit the utility of soils and cause severe losses of this essential resource. Apart from land use and wind, intensive runoff is the major agent for physical degradation of soils. Related processes such as erosion, translocation and accumulation of soil material result in a number of problems.

- A: Soil erosion caused by runoff water leads to an irreversible translocation of soil components. In that process, important mineral and organic sorbents (clay and humus) are being relocated. Geo-ecologically, such relocations strongly affect soil nutrient cycles and thus their utility. At the same time, erosion has a negative impact on the soil depth and the water cycle of the soils e.g. infiltration capacity, soil moisture, and plant available water.

- B: Soil erosion mobilizes a large amount of nutrients and pollutants which are drained into water bodies by surface runoff. This causes eutrophication and pollution, especially in regions of intensive agricultural use.

- C: The accumulation of eroded material causes severe off-site damages which affect agricultural acreage, infrastructure and settlements.

- Soil erosion is strongly connected to surface runoff, which is produced when the infiltration capacity of soils is exceeded as a consequence of long-lasting or intensive rainfall as well as thaw. Runoff is modified by soil texture (soil structure, soil fabric, grain size distribution), vegetation cover, topography and land use intensity. Due to the splash effect of heavy rain, bare soil surfaces are being sealed. This effect significantly reduces infiltration rates. During following rainfall events, runoff is easily produced which induces small scale rill erosion. Converged runoff alongside these natural or artificial drainage pathways increases linear erosion. This process takes place on different scales, ranging from smaller channels (fig. 1.7.1a) to drastic gully erosion (fig.1.7.1b & 1c).

Real time observations and measurements of erosion processes caused by water are very complex and time consuming and therefore only feasible on an exemplary basis. Alternatively, soil profile analyses provide valuable indicators to reconstruct runoff processes and dynamics because soils are interactively connected to all parts of the ecosystem. Traces of soil erosion can be examined quickly and by simple measurements. Form and consistency of these traces are indicative about the processes that lead to physical degradation.

However, to evaluate degradation processes one needs to know the potential status of soil properties under undisturbed conditions as a reference to the actual state. Pedology provides some basic concepts to understand and evaluate the development of soils.

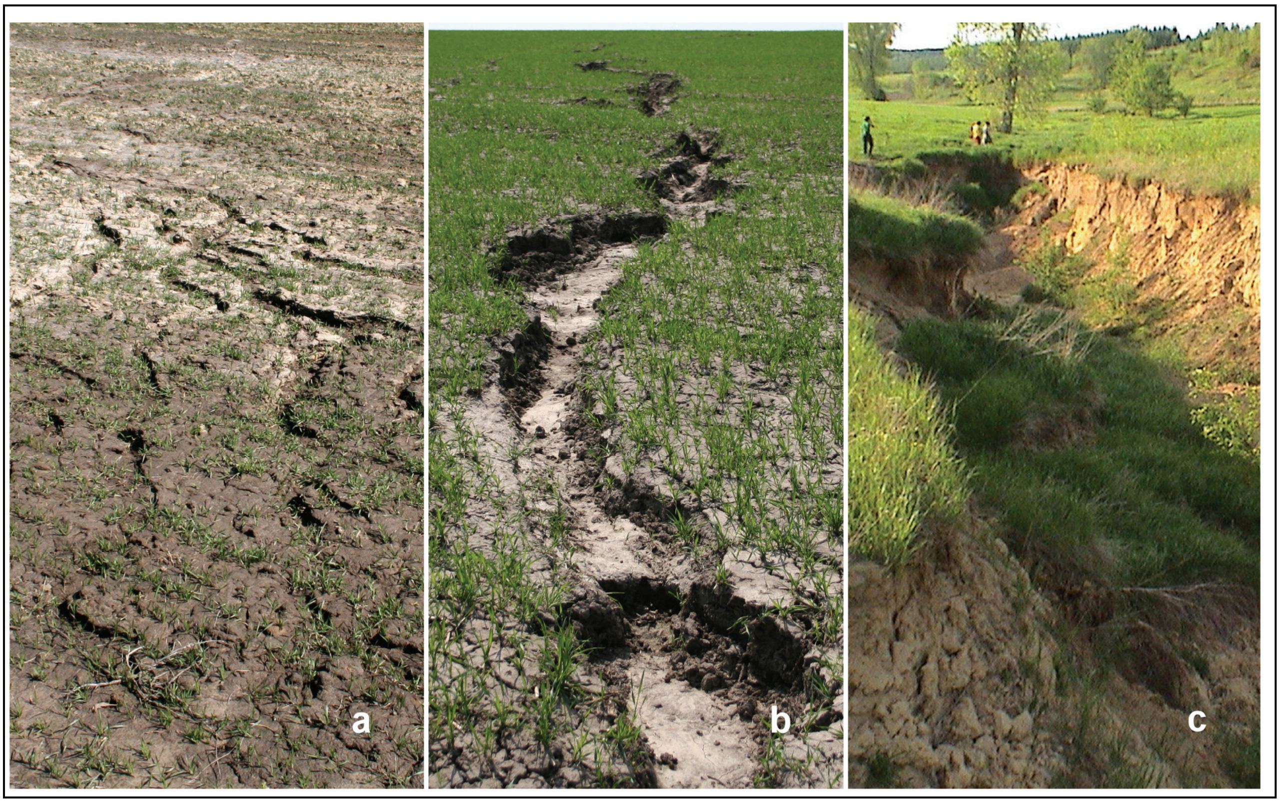


Figure 1.7.1 Erosion forms caused by runoff a.) rill erosion b.) gully erosion c.) severe gully erosion

Concepts & Indicators for soil erosion assessment

The present spatial distribution of soils results from complex soil formation processes. Soil development is driven by geocomponents such as relief, bedrock, water, climate, flora, fauna and land use. Such variable parameters generate different soil types with characteristic horizons. Typical soils in Kazakhstan are Chernozems (A/C profiles), Kastanozems (A/B/C profiles) and Syrozems (Ai/C profiles). To conceptualize soil development temporal and spatial soil sequence models are used.

Soil chronosequences are employed to conceptualize the state and direction of soil evolution (Hugget 1998: 156). Following this model, soil development states are understood as a function of interacting geo-components and time. Therefore, comparable constellations of geo-components will result in similar soil types, meaning the direction of soil evolution will also be comparable. Under relatively stable ecological conditions, soil formation is aiming for a characteristic soil type. These soil types represent the present "end product" within a given geo-component constellation. In continental tall-grass steppe areas of Kazakhstan Chernozems are such typical soil types.

Soil toposequences (*Catena*) are concepts to model characteristic soils by focussing firstly on the influence of the topographic position on the soil development (Martz 1992). Relief has a major impact on soil formation processes. Therefore, a catena can be used to spatially extrapolate the distribution of different soil parameters and types.

Combining both concepts one can model an idealized soil mosaic of a given area. This can be used as a reference to evaluate the impact of degradation processes by analyzing the different states of soil properties between an idealized and a given soil profile.

There are many properties that can be used as indicators to describe the quality of soils and identify soil types (IUSS WRB 2007). The classification is based on the presence or absence of diagnostic horizons. These horizons can be analysed with respect to their development stage and thickness as well as their physical features like colour, texture, and grain size distribution. Other important physical and chemical parameters for characterisation are pH, electrical conductivity and concentrations of soil organic matter (SOM), as well as concentrations of nutrients, heavy metals and heavy minerals.

Methods to determine soil properties

To analyse soil properties simple field methods can be applied. Soil samples can be taken using different soil probes or percussion drill equipment. For a better overview soil- and geo-profiles should be excavated. Based on physical soil properties and the combination of diagnostic horizons, soil types and their current states can be determined. Further physical and chemical soil properties can be measured in the laboratory. Applying the concepts of chrono- and toposequences, point information on soils can be extrapolated to surrounding areas.
With regard to degradation marks like soil profile truncation, compaction or leaching morphological dynamics of erosion and accumulation can be assessed. Furthermore, effects of surface runoff can indirectly be estimated.

The impact of erosion processes can easily be evaluated by focusing on the differences between an investigated soil profile and an expected one within the concepts of chrono- and toposequences. If only a shallow pararendzic soil (A-horizon < 30 cm) on a dry, continental, moderately inclined loess site is found, instead of an expected Chernozem (A-horizon > 80 cm), one can deduce strong erosion in relation to the relief.. In contrast to that, one can anticipate the covering of the original soil by up slope sediments at the corresponding slope foot.

The bigger the deviation between the idealised profile and the investigated one, the more significant was the impact of erosion – and thus the surface runoff.
Such discrepancies are manifested in the erosive truncation of profiles or their colluvial covering. Soil pattern in morphologically active regions display a complex interlacing of erosion and accumulation sites and respectively erosion and accumulation processes. In such areas, surface runoff is a key agent for erosion besides anthropogenic usage and wind.

Additionally, geo-morphological forms can be used to estimate the geo-morphological impact of surface water. Mapping morphological parameters like size, topographical position and orientation of land forms, related water erosion processes can be ranked effectively in spatial and chronological dimensions. This allows detailed and spatially specific conclusions with regards to the dynamics of erosion and their intensity.

By combining and interpreting information about soil and geomorphology, the topographic situation and the pattern of soil erosion and accumulation within a catchment area can easily be identified. Consequently, it is possible to determine zones with an increased demand for soil protection activity. For that matter, the extent of soil erosion or accumulation is a valuable indicator for the vulnerability of a site, with respect to water-bound erosion.

Soil erosion prevention by surface water runoff reduction

Most activities to prevent physical soil erosion aim at the reduction of surface runoff. It can be achieved by keeping a vegetation or crop residue cover, by increased infiltration capacities due to land use measures or by the introduction of landscape structures to prevent convergence and the intensification of surface runoff. Infiltration, the percolation of precipitation and surface water, increases by the improvement of soil fabric, porosity and by avoiding soil capping and compaction.

Depending on soil aggregate stability and the substrate's grain size distribution, unprotected soils are prone to capping. Especially during high-intensity rainfall events, the splash-effect of rain drops causes sheet erosion and can create an impermeable soil surface. The clogging of vertical pores reduces the ability of soils to absorb water (percolation). During the following rain, capping significantly increases surface runoff and related erosion even on gentle slopes.

Figure 1.7.2 Exemplary soil profiles a) slightly eroded Chernozem (profile 6 in fig. 1.7.3) b) severely eroded soil (profile 6 in fig. 1.7.3) c) accumulated humic soil material (profile 1 in fig. 1.7.3) (Photos by C. Schneider)

The following measures are promoted to improve infiltration:

- continuous coverage of agricultural surfaces with vegetation or crop residue (mulch) to mechanically protect the soil surface and to enhance soil biological activity;
- conservation tillage practices (no-till, ridge-till and mulch-till) and direct seeding to improve soil aggregate stability and to increase soil biological activity and soil organic matter contents (Suleimanov et al. 2012; Hickmann 2006).

Apart from advancing soil infiltration capacities, passive and landscape structural precautions are recommended such as:

- contour ploughing preventing artificial runoff pathways;
- slope length reduction through landscape structures to avoid long runoff pathways and to interrupt runoff convergence and intensification;
- permanent vegetation cover of runoff channels and at vulnerable slope positions.

The outlined measures are the basis for conservation agriculture in Kazakhstan. In 2012 about 1.6m ha of agricultural land where already managed with no-tillage practices (Friedrich et al. 2012: 3).

One example for making use of the toposequence concept

This paragraph documents an exemplary study in a Polish loess area. It illustrates the approach of using soils as indicators for water-bound soil erosion. The research area is intensively used by agriculture and characterised by fine grained loess sediments. Precipitation amounts about 650 mm/a with highest sums in spring and early summer (May and June).

The silty and calcareous loess material is highly vulnerable to water erosion. Major erosion events occur during spring-time snow melting and high-intensive convective summer rainfalls (fig.1.7.1b, c). Climatic erosion risks in spring and early summer overlap with the ploughing season and

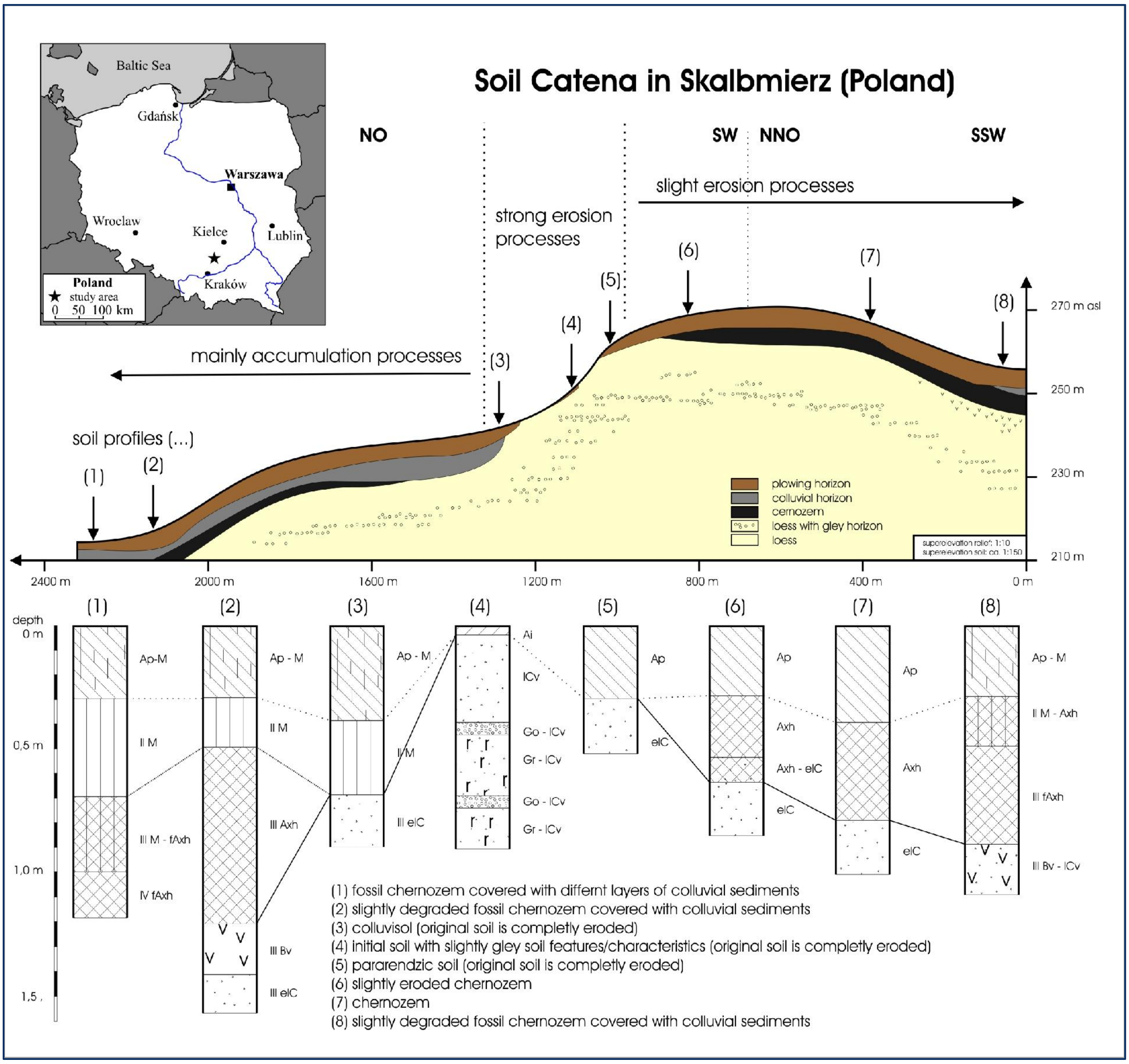


Figure 1.7.3 Example of a soil catena highlighting slope positions which are severely influenced by surface water runoff which is indicated by soil erosion and accumulation (Graphic by R. Schmidt)

therefore unprotected soil surfaces. Thus, land use has an important impact on runoff production and erosion dynamics. Comparable problems occur in Kazakh agricultural areas with rainfed agriculture especially in the North of the country and at the foot slopes of the Southern mountain ranges.

The main soil types in the Polish research area are Phaeozems at different development stages. This Chernozem like soils are rich in organic matter and characterized by slight clay translocation processes (lessivation). Diagnostic horizons (humic A, clayey A/C and mineral C) can be identified using soil colour, soil aggregates and grain size distribution. Areas with severe profile truncation were affected by erosion (see catena fig.1.7.3).

Intensive agricultural land use in the Polish loess area significantly increases the landscape's vulnerability to soil erosion because conventional tillage practices decrease soil infiltration capacities. At the same time, the lack of vegetation or crop residue cover before sowing and after harvesting causes capping and therefore intensifies surface runoff. Steep slopes and convex slope positions are especially prone to be eroded (fig.1.7.3). Converged and concentrated runoff causes linear erosion in mid-slope positions forming typical geomorphological forms (gullies etc.) (fig.1.7.1).

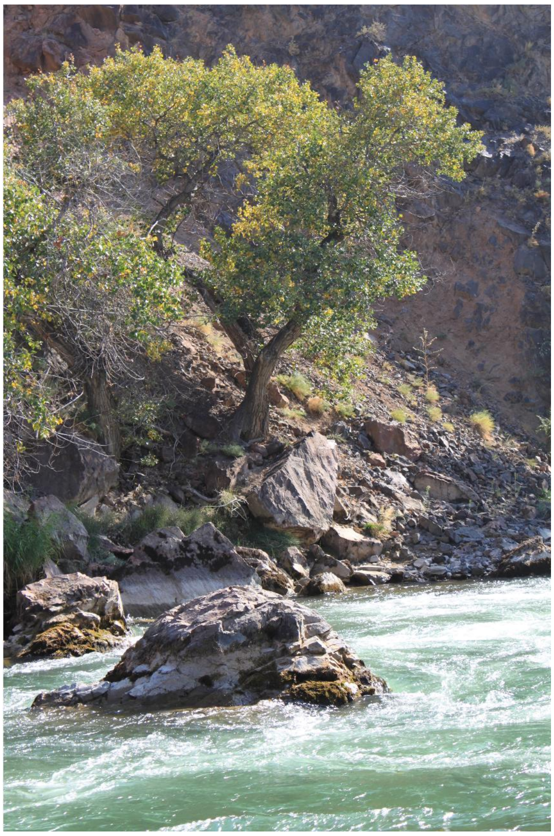
At foot- and toe-slope positions as well as alongside landscape elements (hedges, tree lines etc.) sediments are likely to be accumulated covering previous surfaces (fig.1.7.2c, fig.1.7.3).

This case study shows how the distribution of soil development stages can be used to spatially pinpoint past soil erosion processes. The same basic principles apply for rainfed cultivated agricultural areas in Kazakhstan. Using the toposequence concept analysed soil development stages can be related to slope positions. These positions are highly vulnerable to water bound erosion and currently most likely to be affected by surface water runoff. Finally, appropriate runoff reduction measures can be adopted to different spatial settings.

Integrated Water Cycle Management
in Kazakhstan

IB No. 7535
Signed for publishing 01.10.14. Format 60x84 1/8. Offset paper.
Digital printing. Volume 25,41 printer's sheet.
Edition: 100. Order No.1824.
Publishing house "Qazag university"
Al-Farabi Kazakh National University, 71 Al-Farabi, 050040, Almaty
Printed in the printing office of the "Qazag university" publishing house

E-mail: baspa@kaznu.kz



Tempus