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Managing the Effects of the Climate Change on Water Resources and Watershed Ecology

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1. Introduction

Based on the monitoring data and climate projections, scientists highly agree that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change in the long-run. However, there is no consensus about the degree of impact of human activities on climate change. Using simulation techniques, Intergovernmental Panel for Climate Change (IPCC) estimates the expected changes in the climate on a global scale for different emission scenarios. The results from global estimations are used to drive other simulations that run on regional scaled smaller domains at higher spatial resolution.

Assuming that climate change scenarios will be realized in the future, it is possible to foresee that there will be effects of climate change on watershed ecology and on the water resources. Considering only two of the climate change related variables; temperature and precipitation one can conclude that

- Risks of flooding may increase.
- Droughts may happen more frequently and for longer periods directly affecting the water demand changing the quantity and quality of available water.
- Increase in water demand may result in insufficient capacity of reservoirs and transfer of water from other watersheds might be necessary.
- Changes in water quantity and quality will in turn affect food availability, stability, access and utilization.
- Water quality of surface runoff from urban and rural areas may change.
- Function and operation of existing water infrastructure (including water treatment, hydropower, drainage and irrigation systems) may be affected.

This chapter is devoted to the impacts of climate change on freshwater resources; their availability, quality, quantity, uses and management is evaluated. Impacts on ecology are mentioned. Several management alternatives to reduce the potential adverse effects of climate change are identified; merits and tradeoffs involved are discussed. The discussions on this chapter is about what the ecological impacts of climate change on aquatic ecosystems and water resources will be and what precautions can be taken to sustain watershed ecosystems and water resources together with the demands of our socioeconomic system rather than "how we can prevent the climate change".

1.1 A general summary of climate change

In the last two decades, global climate change has continuously been gaining importance. Scientists from different disciplines agree that our climate is continuously changing. The question open to discussion and debate is the importance and the relative influence of human activities on the climate.

The first study related to climate change was initiated in California University by a climatologist named Charles Keeling. In 1958, he started to monitor the amount of atmospheric carbon dioxide in Mauna Loa observatory located on Hawaii. His studies, which were continued by his son Ralph Keeling after his death, indicated that atmospheric carbon dioxide is continuously increasing. Figure 1, also known as the Keeling Curve illustrates the trend of this increase.

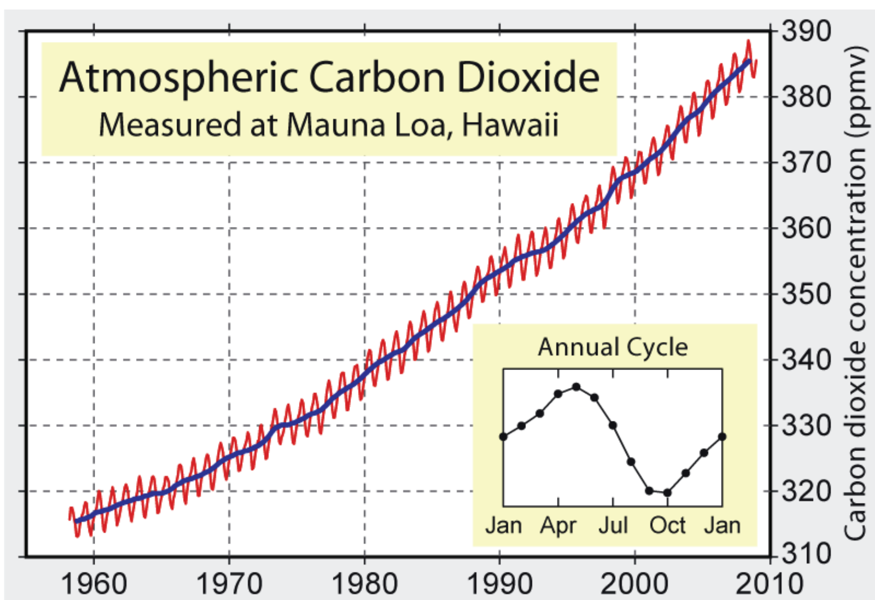

Fig. 1. Keeling curve

The atmospheric carbon dioxide investigation of Charles Keeling is considered to be the first milestone in climate change studies.

In 1970's and 1980's climate change was usually considered as global warming by scientist from various disciplines and interpreted according their knowledge. In late 1980's however it was clear that a more integrated approach is needed to investigate the climate change. Global climate change was considered a complex topic with many aspects and policy and decision makers needed objective information on climate change including

- Its reason
- Environmental and socioeconomic effects
- Possible solutions

To cover these needs, World Meteorological Organization (WMO) and United Nations Environmental Programme (UNEP) founded together the International Panel of Climate Change (IPCC) in the year 1988.

Since early 1990's, IPCC published comprehensive reports in regular intervals the last one being published in 2007 (IPCC, 2007). Simulation results from IPCC modelling studies indicated that without any limitations in human activities related to industrial emissions, 1.8ºC of global temperature increase and 6 – 30 cm sea level rise may be expected 2030 taking the beginning of the industrial revolution (second half of the 18th century) as reference.

Intergovernmental Panel on Climate Change (IPCC, 2007) refers in the Fourth Assessment Report, AR4, to the warming of the global climate system and states that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely [this likelihood statement can be interpreted as probability in excess of 90%; comment added] due to the observed increase in anthropogenic greenhouse gas concentrations" (Szwed et al., 2010). It is also expressed that on the global average, surface temperatures have in¬creased by about 0.74°C between years 1906 and 2005 during which the warming has not been steady and not kept the same both temporally and spatially (IPCC, 2007). According to the recordings taken since 1901 only a few areas have been cooled, among which one of the most notable one is the northern North Atlantic near southern Greenland. However, during this period warming has been experienced more over the continental interiors of Asia and northern North America. As referred by IPCC (2007), the most evident warming signal has occurred in parts of the middle and lower latitudes whereas the duration of the frost-free season has increased in most mid- and high-latitude regions of both hemispheres. Besides, most mountain glaciers and ice caps have been shrinking since 1850s.

Observations so far indicate that over most land areas, cold days and nights have got warmer and fewer, while hot days and nights have got warmer and more frequent. Area affected by drought has been increased. This trend is expected to continue in the future.

The effects of climate change have been highly sensed in sectors like agriculture, energy and water related applications. As stated by Szwed et al., (2010), agriculture in the northern Europe has been temperature-restricted, while in the south it has been water-restricted. Both conditions may have lead to decrease in the crop yields and require the selection of new irrigation techniques, new crop patterns etc. for the sustainability of agricultural production. Water-related studies frequently mention that water budgets may become increasingly stressed. High evapotranspiration and low precipitation in summer leads to depletion of the water storage.

Moreover, researches and model-based studies indicate that weather-related extremes are expected to get more frequent and/or more severe and coping with these events will become more difficult. Countries facing such conditions are attempting to take mitigation measures and develop national and/or regional adaptation strategies.

2. Simple methods to quantify the climate change

2.1 Data

Data related to climate change are on two different temporal scales. The first of these data is the so-called paleoclimatological data that is indirect. Stable isotope data dating back hundreds thousands of years back is used to reconstruct the past atmospheric composition and basic atmospheric conditions such as temperature, precipitation. The second type of data is the historical data from observations dating approximately two centuries back at most. Long term time series of meteorological data can be used to analyse the recent climate dynamics.

Meteorological data can be obtained from state agencies; some of the free data is available on the internet as well. WMO is responsible to organize and manage the meteorological data globally. Meteorological data on territories without meteorological stations can be interpolated using many techniques included models. Results obtained using these techniques are post processed, reanalyzed and published; usually on regional scale such as Europe for example. There are several European community projects that provide such data.

Globally, meteorological data from 1960 to 2000 was used to calibrate and validate global climate change models that will be briefly described in the next section.

2.2 Models related to prediction of climate change

There is not a general term of “climate change prediction model”. Several models on different spatial and temporal scales are linked to provide high resolution hydrological forcing data on changed climate, which will help to predict the response of watershed ecosystems. Each of these type models are described before.

2.2.1 General circulation models

Global Circulation Models (GCM) solve the geophysical fluid dynamics of the atmosphere. They have the same general structure as the numerical meteorological models used for weather prediction. The main difference is that weather prediction models are run for several days or a week, while GCMs are run years even centuries. Therefore GCMs have to be developed using energy conserving algorithms. Another difference is the spatial and temporal discretization. The weather prediction models are run on a horizontal resolution of several ten kilometres, whereas GCMs have a horizontal resolution of several degrees of longitude and latitudes.

Climate change related studies are conducted using global Atmosphere-Ocean General Circulation Models (AOGCM). AOGCMs provide results that give general information on global scale and boundary forcing for higher resolution regional climate change models. Seveal well known AOGCMs are briefly described in following paragraphs.

Hadley Centre Coupled Model, version 3 (HadCM3) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom (Gordon et al., 2000; Pope et al., 2000; Collins et al., 2001). It was one of the major models used in the IPCC Third Assessment Report in 2001. HadCM3 includes two components; the atmospheric model HadAM3 and the ocean model that includes a sea ice model. Simulations often use a 360-day calendar, where each month is 30 days. HadAM3 has a horizontal resolution of 3.75×2.5 degrees in longitude × latitude. This gives 96×73 grid points on the scalar (pressure, temperature and moisture) grid; the vector (wind velocity) grid is offset by 1/2 of a grid box resulting in a resolution of approximately 300 km. The timestep is 30 minutes (with three sub-timesteps per timestep in the dynamics).

The coupled global model ECHAM4/OPYC3 was developed in co-operation between the Max-Planck-Institute for Meteorology (MPI) and Deutsches Klimarechenzentrum (DKRZ) in Hamburg, Germany. The ECHAM model is an atmospheric circulation model. The reference horizontal resolution is 300 km , but the model is set up to use finer and coraser resolutions. The time step at reference horizontal resolution is 40 minutes. ECHAM4 is coupled with ocean circulation model OPYC3.

2.2.2 Regional climate models

Regional climate models (RCM) have a higher spatial and temporal resolution. They provide more detailed information then the GCMs, however they work on a smaller domain. RCMs work by increasing the resolution of the GCM in a small, limited area of interest. An RCM usually cover an area the size of Western Europe or southern Africa. GCMs determine very large scale effects of changing greenhouse gas concentrations, volcanic eruptions etc. on global climate. The climate (temperature, wind etc.) calculated by the GCM is used as input at the open boundaries of the RCM. RCMs can resolve the local impacts given small scale information about orography, land use etc., giving weather and climate information at fine horizontal resolutions such as 50 or 25km. The outputs of RCMs are used to force finer spatial resolution models that are used to predict the response of watershed ecosystems to climate change that are briefly explained in the next section.

2.3 Models related to prediction of response of watershed ecosystems to climate change

Many environmental models that are useful to predict the response of watershed ecosystems to climate change are available. Most of these models are freely available, even open source. Giving detailed information about environmental modelling is beyond the scope of this text. For such information, the reader is referred to other standard texts such as Schnoor (1996), Chapra (2008) or Simonovic (2009).

Basically, there are two general types of models that are used to predict the response of watershed ecosystems to external forcing such as climate change: The watershed models and the aquatic ecosystem models.

2.3.1 Watershed models

Watershed models are derived from hydrological models, usually from a formerly known hydrological model so that they contain all the key hydrological processes. They also contain sediment transport and terrestrial biogeochemical cycle related processes.

Since 1960's many hydrological models were developed and some of them evolved to general purposed watershed models. However, just a minor fraction of them were designed to simulate the hydrology and ecology of entire watershed using the coupled modelling approach and even fewer of them were continuously developed and became widely used, freely available open-source modelling tools. SWAT (Arnold et. al., 1999) and HSPF (Brickner et. al, 2001) are good examples for such modelling tools. WASH123D (Yeh et. al, 2005) is more comprehensive than SWAT and HSPF as a hydrological model but has simpler water ecology related facilities. MIKE-SHE is also capable to simulate the watershed hydrology and ecology; however it is neither free nor open source; and needs additional products such as MIKE-11 to be coupled with. Other models such as SWAP (Van Dam, 2000; Van Dam et al., 2008), PIHM, Hydrogeosphere (Therrien et al, 2010) are general hydrological model taking almost all the compartment of the hydrological and can be easily linked to landscape and water ecology models.

Among all the models discussed SWAT and HSPF are the most widely used ones and generally most applicable ones. The applicability of SWAT was reviewed by Gassmann et al

(2007). There is also a literature database on SWAT website, which indicates that SWAT and its variants were applied 816 times in studies published by peer reviewed journal articles reporting hundreds of applications on different watersheds all over the world. HSPF on the other hand is widely used as well. The bibliography provided by developers contains more than 300 entries. The performance of SWAT and HSPF were compared by several authors (Im et al., 2003; Nasr et al., 2004; Saleh and Du, 2004; Sigh, et al., 2004), where both models were applied to the same watersheds. In these studies, both models produced comparable results; however HSPF produced slightly more accurate results in river discharges, whereas SWAT was better in reproducing the nutrient loads.

2.3.2 Aquatic ecosystem models

Aquatic ecosystem models are the successors of water quality models; however there is not a standard definition of a "water quality model" and "a water ecology model" or a very strict border between them. Many well known aquatic ecosystem models or their predecessor water quality models were developed in late 1970s. There are many well written texts related to water quality and aquatic ecosystem modelling, so the reader is referred to those texts. Information related how to obtain them can be reached by simple internet queries. Following paragraphs will give brief information on some well known models that may be useful for aquatic ecosystem modelling especially on estimating the possible impacts of climate change on aquatic ecosystems.

The Water Quality Analysis Simulation Program (WASP) is a water quality model that was developed in early 1980s by United States Environmental Protection Agency. It is a good model for initial studies. The latest version of WASP (Version 7.5) includes an advanced eutrophication module that can simulate the nutrient cycle and primary production up to three phytoplankton groups as well as the detritus cycle. Unfortunately higher trophic levels of the aquatic food web are not covered by the advanced eutrophication module. WASP can be driven by external hydrodynamic simulation models.

CE-QUAL-W2 is a hydrodynamic and water quality model in 2D (longitudinal-vertical). It is applicable to large watershed/water resource systems that contain these types of water bodies such as lakes, rivers and reservoirs. The current model release enhancements have been developed under research contracts between the Corps and Portland State University. The model can simulate basic eutrophication processes such as temperature-nutrient-algae (multi groups)-dissolved oxygen-organic matter and sediment relationships. Additionally, zooplankton (muti groups) can also be simulated.

CE-QUAL-R1 is a one dimensional (vertical) reservoir model developed by Hydrologic Engineering Center (United States Army Corps of Engineers). It can simulate nutrients and phytoplankton (three groups) and zooplankton like CE-QUAL-W2. Additionally, a simplified simulation of fish can be conducted. The model is designed to simulate anaerobic processes and dynamics of reduction processes as well.

AQUATOX is originally developed to assess the fate and effect of chemicals in experimental containers. With the improvements of former versions of AQUATOX, the model has reached the 3rd release, which has the capability of risk assessment combined with the fate and effect of pollutant and toxic chemicals in the aquatic environments. The way AQUATOX characterizes the aquatic system is different from many other models do. Mostly the ecosystem models represent the individuals by the changes in their numbers; hence, they called as population models. However, AQUATOX simulates the ecosystem by changing the concentrations of all components such as chemicals, sediments, and even organisms including the ones on the higher trophic levels of food web. The model is intended to assess dynamic effects of various stressors such as temperature, toxic chemicals, nutrients, sediment; which is applied to aquatic environments from experimental tanks to lake systems.

3. Effects of climate change on water resources and watershed ecology

Climate change may have short and long term effects on watershed ecosystems resources. Short term effects take place because of the extreme events that are related to climate change. Floods are good examples for such extreme events. During a flood shock loading of sediments, organic matter and nutrients can be transported into lentic freshwater ecosystems such as lakes and reservoirs. Aquatic ecosystems respond to such sudden forcing by instantaneous changes in water quality. Recovery of the system that may take from a couple of weeks up to a couple of years depends on following factors:

- the intensity of the effect
- internal structure of the system
- operating schedule (in case of engineered systems)

Long term effects on water resources occur due to climatic trends and extended periods of droughts.

The relation between the components of the historical water balance and climatic variables may be needed as reference in order to quantify the effect of climate change on the water balance of a watershed. This task is straightforward if historical data on both; the climatic variables and the water balance components exist. If one of them is missing the other one can be reconstructed using simulation techniques. Kavvas et al., (2009) used a regional hydro climatic model (RegHCM-TE) for Tigris-Euphrates watershed located in the Middle-East for reconstructing the historical precipitation data to perform water balance computations for infiltration, soil water storage, actual evapotranspiration and direct runoff.

3.1 Change of water quantity reaching the water resources

Climate change may result in average temperature and total precipitation increase. However the temporal and spatial heterogeneity of meteorological parameters may increase as well resulting in prolonged dry season and increased in flood frequencies in wet season. Average temperature in the warm season may increase and average temperature in the cold season may decrease as well.

Changes in precipitation and temperature do not only change the total amount of runoff to freshwater systems from their catchments but also the temporal distribution of water inputs. Generally, intensification of the global hydrological cycle is expected as a result of temperature increase. However, if the land surface hydrology is dominated by the winter snow accumulation and spring melt, temperature increase is likely to cause a change in the outflow hydrographs of the watersheds where time of peak flow will be shifted towards winter. Detailed information related to this phenomenon is provided by Barnett et al., (2005) in great detail. Forbes et al., (2011) analyzed the water cycle in a small snow dominated

Canadian catchment (Beaver Creek, Alberta) using a hydrological simulation model (ACRU agro-hydrological modeling system) and concluded that regions with snowmelt-dependent water supply may experience severe changes to the hydrological regime due to temperature increase. The consequences were reported by Forbes et al., (2011) as less available soil water with potential negative impacts on agriculture, and also increased stresses for the natural vegetation, lower streamflows in late summer and fall with potentially adverse impacts on the aquatic ecosystem and anyone who withdraws water from the river.

Furthermore, as temperatures rise the winter precipitation may shift from snow to rain and the timing of peak streamflows in many continental and mountainous regions will change. The spring snowmelt peak flow may shift to earlier days of the year or even get eliminated entirely and winter flows increase (Kundzewicz et al., 2008).

Changes in frequencies and intensities of extreme events such as floods and droughts are projected as well. According to IPCC (2007), the proportion of total rainfall from heavy precipitation events will increase and tropical and high latitude areas will experience increases in both the frequency and intensity of heavy precipitation events.

Döll & Flörke (2005) stated that many of the current water-stressed areas will suffer from decreasing amount of water since both the river flows and the groundwater recharges are expected to decline. In addition, Kundzewicz et al., (2008) reported that drought frequency is projected to increase in many regions, in particular, in those areas where reduction of precipitation is projected.

3.2 Capacity shortage in river/reservoirs systems because of the increased water demand and water transfer among watersheds

Temperature increase may increase evaporation from surface waters and evapotranspiration and thus water loss from plants and soil will result in increased irrigation water demand. However, Barnett et al., (2005) states that there is little agreement on the direction and the magnitude of historical and/or predicted evapotranspiration trends. Temperature increase alone is expected to enhance evaporation and eventually evapotranspiration. On the other hand, temperature increase also affects other variables such as wind speed, humidity, cloudiness that have their amplifying/dampening effects on the evaporation and evapotranspiration as well. Therefore, the magnitude and the direction of the total response of evapotranspiration to temperature increase should be considered as spatially and temporally variable. This should be considered when deciding on the operational schedule of reservoir systems and especially on those that have the purpose of irrigation water storage and supply.

Temperature increase may also stimulate water consumption. Increased water consumption may result in future shortage of reservoir capacity that is sufficient today. In this case two options are available:

1. Promoting decreased water consumption
   - change in way of life in urban areas
   - change in crop patterns/irrigation methods
   - shifting to water saving processes in the industry
   - application of ecological sanitation in rural areas

2. Transfer of water from another watershed. Water transfer from other watersheds should be planned carefully and managers should not only consider the quantity but also take into account the ecological effects on both watersheds. More information on this topic is given in the mamagement section.

According to Mirza et al., (2003) the benefits of expected annual runoff in several regions such as South-Eastern Asia will be tempered by negative impacts of increased variability and seasonal runoff shifts on water supplies. Flood risk will increase especially in low-lying river deltas. Furthermore, additional precipitation during the wet season in those regions may not solve the water stress problem occurring in dry season if the extra water cannot be stored because of the shortage of reservoir capacity. Similarly; Barnett et al., (2005) states that changes in precipitation patterns will not offset the problems as associated with warming.

3.3 Change of water quality in runoff

Another response of ecosystems to climate change is the change in the quality of surface runoff from agricultural land, forests and urban areas.

Changing meteorological conditions may necessitate changes in crop patterns and thus manure/fertilizer/pesticide applications and irrigation schedules may change. Some areas may loose the ability of any agriculture whereas other frozen wastelands may become appropriate for agriculture. Hence, water quality of surface runoff from agricultural areas is expected to be affected in the future due to the direct and indirect impacts of climate change.

Forests, depending on their ecological characteristics emit nutrients and organic matter that are transported into aquatic ecosystems sooner or later. Forest ecology is complex and more inertial compared to aquatic ecology. In other words, their response to external forcing is slower and less predictable making it much harder to estimate the short term effects of climate change on surface runoff quality from the forests. Annual and seasonal average temperature increase generally eases the photosynthesis rate and plant yield changing vegetation and forests. Increase in temperature and changes is other meteorological variables may cause forests to succeed in higher elevations. However, extreme increase in temperature may result in higher plant respiration rates and shift the photosynthesis-respiration balance towards respiration. Droughts have an adverse effect on forests favouring succession of steppes and shrubs. Soil organisms will be affected by climate change as well, thus the biogeochemical cycles are likely to be shifted to different equilibria.

Change in both natural vegetation and soil biology will cause different water quality and quantity from forest runoff.

Increase in storm event intensities and frequencies will result in more wastewater containing storm water release to receiving water bodies in case of combined sewer systems. Also sudden events related to precipitation and temperature may also affect the performance of wastewater treatment systems. In case of droughts, accumulation of contaminants on land can be expected as there will not be storm event for extended periods. Hence, a storm event following an extended dry period will have an increased shock loading effect on water resources.

3.4 Deteoration of water quality in aquatic ecosystems

Climate change may affect the ecological processes in lentic ecosystems which in turn will affect the water quality. Increase in average annual water temperature affects the primary producers following ways:

- Temperature changes will affect both; the photosynthesis and the respiration rates. Initially, increases in temperature will promote higher photosynthesis and respiration rates. However, for each group of primary producers, there is an optimum temperature range. If the water temperature exceeds the upper limit for optimum conditions, temperature stress will decrease photosynthesis rates and increase respiration rates. This mechanism will accelerate the nutrient recycle and making nutrients available for primary producers adapted to higher temperatures causing a shift in dominant phytoplankton group. More increase of temperature may completely suppress some phytoplankton groups and/or cause sudden breakdown of their blooms eventually leading to decreased water quality.
- Phytoplankton groups that can adapt to higher temperatures for example cyanobacteria will be favoured. Cyanobacteria that are generally better adapted to higher temperatures may dominate the algal community. Genera such as *Anabaena* and *Aphonizomenon* produce algal toxins, taste and odour problems. Some species of cyanobacteria are capable of nitrogen fixation and hence increase nitrogen in aquatic ecosystems through internal loading.
- More days with suitable light conditions for algal blooms or longer photoperiods during a day may occur if the cloud cover changes due to the climate change. Those conditions may extend the vegetation period as well as earlier blooms may be possible. A large portion of the nutrient inputs to lotic ecosystems generally occur in late winter and early spring related to rain events and snowmelt. In this period although the nutrient concentrations increase in water, lower water temperatures limit phytoplankton growth. However, if the water temperatures increase, two factors needed for phytoplankton growth, more suitable temperature and high nutrient concentrations, will synergistically favour phytoplankton growth. If these conditions are followed by better light availability, phytoplankton blooms will be stronger and more frequent and adversely affect the water quality.

Increase in water temperature will increase the biological activity in aquatic ecosystems, hence increase the oxygen demand. Ironically, higher temperature decreases the saturation concentration of dissolved oxygen in water as well. Combining these effects with accelerated primary production and more internal detritus loads as its conclusion, it is possible to foresee that oxygen scarcity, hypoxia or anoxia events may increase especially in deep lakes. These conditions cause stress for aquatic organisms increasing their mortality, which also means even more detritus. Those changes in internal dynamics of aquatic ecosystems are likely to decrease their capacity to assimilate external organic matter loads.

4. Effects of climate change on water resources systems

Climate change may impact the components on man-made water resources systems as well.

Deteoriation of reservoir water quality may cause operational problems related to equipment. Those problems are:

- Anaerobic corrosion: Anaerobic bacteria will reduce certain substances, such as sulphate, and consequently corrosion may come about. The oxidation of iron atoms into ions and ferrous sulphate ions reduced sulphide ions act as a catalyst.
- Increased suspended sediment load and sedimentation may decrease reservoir capacity.
- Increased primary production and phytoplankton biomass may cause clogging in filter systems.

Increase of organic matter in raw water may increase energy and chemical consumption in water treatment systems. Possible problems are:

- Increased odour
- Increased colour and turbidity
- Increased algal toxins because of cyanobacteria growth

As stated previously, climate change is likely to increase the water demand that will increase water abstraction through the water distribution network. This situation increases the operational load on water distribution and may cause problems such as pressure drop in water distribution networks followed by urban water shortage risk and related problems listed below:

- shortage of water storage volumes
- pumping stations
- increased costs
- public health problems

5. Management

It is stated by Rosenzweig et al., (2007) that some climate change impacts on hydrological processes have already been observed and further changes are projected. Thus, mitigation measures are needed to be taken as well as adaptation to climate change is necessary. Below common adaptation measures are referred.

5.1 Efficient and effective use of water

When water demand increases and water availability decreases one of the most widely used solution towards decreasing water more consumption is using the available water effectively and more efficiently. Water demand management considers measures to improve efficiency of water use.

Among sectors, agriculture is the leading sector in terms of water consumption. Climate change is expected to directly and indirectly increase demand for agricultural irrigation. Adaptation measures to climate change in the agricultural sector include changes of agrotechnical practices (e.g., use of crop rotation, advancing sowing dates) and introduction of new cultivars (heat-wave- and drought-tolerant crops). Soil moisture should also be conserved (e.g. through mulching). Besides, timing and frequency of irrigation need to be optimized considering the crop requirements. This is important for reducing irrigation return flows which in turn deteriorates the quality of the receiving water.

Industrial water consumption may also be reduced by developing less water using technologies as well as in-plant control measures. Clean technologies should be preferred due to their optimized water consumption.

Domestic uses may be decreased by encouraging public to use water-saving home appliances, through water pricing, legal sanctions and raising public awareness. In the big cities in developing countries, water loss through leakages in the water distribution lines constitutes a significant amount. Thus, it must be aimed to decrease water losses below 10% by renewing the old pipelines.

5.2 Alternative water resources

In cases of severe water scarcity, reducing water consumption may not be a remedy and thus searching for alternative water resources may become crucial.

Desalination of seawater or brackish water is considered as an important option of producing freshwater. Recent technologies and advances in the sector allow producing freshwater at affordable costs when higher amounts are intended. However, water withdrawals for desalination purposes may alter the well-being the related ecosystem. Thus, it is necessary to take into account the environmental impacts that might occur due to the planned water withdrawals. Also brine that is produced in desalination process should be properly disposed.

Another alternative source is reuse of treated wastewater. It is known that treated wastewater may be used for irrigating green land, parks and gardens in big cities. It can also be used for irrigating agricultural land if the national standards are satisfied in terms of irrigation water quality. Industries can also utilize treated wastewater in their processes providing that the quality of the goods manufactured remain unchanged (Asano et al., 2007).

Aquifers can be thought as storages where water loss through evaporation is relatively low. Thus, recharge of groundwater aquifers with treated wastewater is applied in different countries such as Israel and Spain (Esteban & Miguel, 2008; Salgot, 2008). However, it should be underlined that advanced treatment is necessary to protect the aquifers from pollution.

Another option is ecological sanitation (ECOSAN) practices. By such applications generated wastewater is separated into three streams at the source (yellow water, grey water and black water) that may be recycled after applying simpler treatment techniques. For example treated grey water may be used for irrigation and for recharge of aquifers. However, in most of the cases existing and usually old fashioned infrastructure is not compatible with ECOSAN. Reuse and/or disposal of each wastewater stream should be carefully planned. For example, yellow water could be used instead of fertilizer but if not desalinated salinity in human urine can harm the crops and the soil (Beler-Baykal et al., 2011).

5.3 Inter-basin water transfer

Szwed et al., (2010) states that water transfer from an area of relative abundance to an area of scarcity may smooth the spatial water variability. It is applied in many arid and semi-arid regions. Three points are important in water transfer: Feasibility regarding engineering works, hydrological conditions and ecological conditions of the basins. Pre-screening in terms of engineering works focus on costs of the work and on the length of water transmission lines. Besides, head loss/energy consumption of the pumps, natural and artificial barriers along the pipeline and its vicinity are also important factors to be considered.

Inter-basin water transfer depends on the availability of excess water from where the water is withdrawn. Especially the climatic conditions of both basins gain importance. If both basins face drought conditions in the same years, water transfer among them should not be considered as a feasible option. Both basins must be surveyed prior to realization of water transfer regarding their hydrological characteristics. During these surveys, long-term hydrological data must be analyzed. Watershed ecology is equally important. Socio-cultural conditions and economical characteristics should also be taken into consideration and sustainability should be kept in mind during water withdrawals. There are still contradicting opinions on inter-basin water transfer. They argue that inter-basin water transfer may no longer be viable in a future with climate change, as climate change stresses almost every source of freshwater. Also taking more water from the natural system has biological, ethical, and increasingly legal limitations (Karakaya and Gonenc, 2005; Hall et al., 2008). Consequently, it is advised to consider inter-basin water transfer to be considered as the last solution to water scarcity.

5.4 Maintaining the sustainability of watershed ecosystems

Natural aquatic ecosystems are among the important water resources supporting life. It is very important to maintain the ecological flows of these systems. Ecological flows are usually determined by some practical statistical approaches, assumptions and methods supported by scientific research conducted at site. During these studies it must be considered that aquatic ecosystems are in interaction with terrestrial ecosystems. Thus, any change in aquatic or terrestrial ecosystem will have an effect on the other one. For example, the decrease in surface water levels will affect the groundwater levels and dependent ecosystems. Evapotranspitation increase due to climate change has also effect on the decrease of groundwater levels. As this condition may lead to change in the vegetation cover which in turn lead to habitat change regulation of groundwater use becomes more important. As renewal of groundwater lasts long, planning must be done prior to facing water scarcity.

5.5 Revision of infrastructure

Changes in water quality in water resources will necessitate revision of existing water-related infrastructure. New components of the infrastructure should be designed according to possible extremes that would occur. Resilience of the infrastructure should also be enhanced.

Water treatment systems must be designed and operated according to drinking water standards under raw water inflow with varying water quality. On the other hand, different wastewater treatment options that seem not feasible today may be available in a world with higher annual average temperature. One example is the upflow anaerobic sludge blanket (UASB) process that is used to treat municipal wastewater in warmer countries such as India currently. Such technologies that are more cost-efficient could be applied in higher latitudes once further meteorological conditions change due to climate change.

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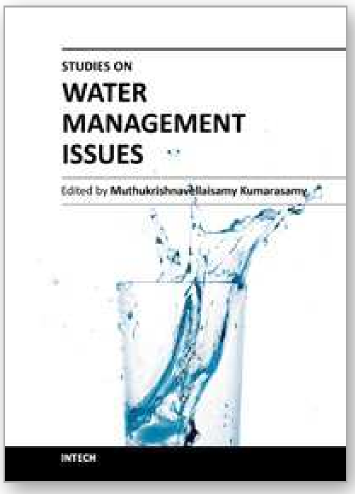

Studies on Water Management Issues

Edited by Dr. Muthukrishnavellaisamy Kumarasamy

ISBN 978-953-307-961-5

Hard cover, 274 pages

Publisher InTech

Published online 18, January, 2012

Published in print edition January, 2012

This book shares knowledge gained through water management related research. It describes a broad range of approaches and technologies, of which have been developed and used by researchers for managing water resource problems. This multidisciplinary book covers water management issues under surface water management, groundwater management, water quality management, and water resource planning management subtopics. The main objective of this book is to enable a better understanding of these perspectives relating to water management practices. This book is expected to be useful to researchers, policy-makers, and non-governmental organizations working on water related projects in countries worldwide.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Ali Erturk (2012). Managing the Effects of the Climate Change on Water Resources and Watershed Ecology, Studies on Water Management Issues, Dr. Muthukrishnavellaisamy Kumarasamy (Ed.), ISBN: 978-953-307-961-5, InTech, Available from: http://www.intechopen.com/books/studies-on-water-management-issues/managing-the-effects-of-the-climate-change-on-water-resources-and-watershed-ecology

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