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Governing for Growth in Georgia

METHODOLOGY FOR THE CALCULATION AND FORECAST OF WATER BALANCE AT RIVER BASIN LEVEL FOR THE CONTEXT OF GEORGIA

USAID GOVERNING FOR GROWTH (G4G) IN GEORGIA

30 OCTOBER, 2015

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ACRONYMS

CAMS	Catchment Abstraction Management Strategies
DABC	Built Environment and Construction Engineering
DAER	Department of Aerospace Science and Technology
DBM	Data-Based Mechanistic Model
DEP	Department of Environmental Protection
DICA	Department of Civil and Environments Engineering
UK EA	Environment Agency of the United Kingdom
EIA 3D	Environmental Impact Assessment Three-Dimensional Numerical Finite Difference Hydrodynamic Model
EOEEA	Executive Office of the Energy and Environmental Affairs
EPA	Environment Protection Agency
ERDAS	Earth Resources Data Analysis System
EU	European Union
G4G	Governing for Growth in Georgia
GEO	Group on Earth Observations
GEOSS	Global Earth Observation SYSTEM of SYSTEMS
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security Programme
GoG	Government of Georgia
GPS	Global Positioning System
IIRS	Indian Institute of Remote Sensing
IRS	Indian Remote Sensing
km	Kilometer
LUP	Land Use Planning
MassGIS	Office of Geographic Information
MODFLOW	Three-Dimensional (3D) Finite-Difference Groundwater Model
NBSS	National Bureau of Soil Survey and Land Use Planning of India
PAN	Panchromatic Sensor Data
SOI	Survey of India
TIA	Total Impervious Area
TM	Thornthwaite and Mather
US EPA	United States Environmental Protection Agency
USAID	United States Agency for International Development
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WEAP	Water Evaluation and Planning system
WRMP	Water Resource Management Plan
WFD	Water Framework Directive

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1 INTRODUCTION

Governing for Growth in Georgia (G4G) is a USAID 5-year initiative aimed at supporting the Government of Georgia to create a better enabling environment in which legal and regulatory reforms are fairly and transparently conceived, implemented and enforced providing a level playing field for small and medium size enterprise growth.

G4G aims to strengthen capacity of both, public and private sectors, to effectively cooperate on elaboration of the legislative changes required for the identified reforms through an inclusive consultative process.

To achieve the goal, G4G supports inclusive public-private dialogue for the effective formulation of reforms to drive economic development nurtured through transparent and accountable oversight of the state.

One component of G4G is Water Resource Management, providing assistance to the GoG in removing current and future conflicts in water use and consumption in Georgia. Under Component 3, USAID is developing a process to be used by the Government of Georgia (GoG) in developing a water resource management plan for river basin that will analyze the future water balance for each river basin and a water allocation for competing water consumers and user.

G4G selected the Aragvi River Basin as the initial water basin to establish a process for developing water resource plans across Georgia in order to identify and find radiation measures for conflicts of water use. G4G is now evaluating different approaches to forecasting water supply and water use/consumption for the Aragvi River.

Water balance can be applied to many different systems: it can refer to the ways in which an organism maintains water in dry or hot conditions, most often in reference to plants or arthropods. In hydrology, a system can be one of several hydrological domains, such as a column of soil or a drainage basin, and water balance is normally used to describe the flow of water in and out of the system and determined as a ‘’Numerical calculation accounting for the inputs to, outputs from, and changes in the volume of water in the various components of the hydrological cycle, within a specified hydrological unit and during a specified time unit, occurring both naturally and as a result of the human induced water abstractions and returns’’[1]

Water balance can be calculated in different ways depending on the availability of hydro-meteorological data and technological capacity to estimate the missing data. Depending on the methodology adopted, the water balance can serve different purposes:

a. In absence of permanent monitoring systems, a prospective water balance can be drawn up from historic data to estimate the average availability of the resource to satisfy the water demand at the time of the calculation;

b. When extensive real time hydro-meteorological data are available, the water balance can be calculated to estimate the water withdrawal over a defined period of time (day, week, month, year etc.);

c. Water balance calculation can be used by water utilities to operate reservoirs and water distribution systems in order to ensure the most effective distribution of the resource.

In the case of a river basin, the most common methodologies for calculation of the water balance rely mostly upon extensive monitoring activities of the current and past water and ecological situation. The equivalent of Georgia’s Hydromet Department of the National Environmental Agency is normally in charge of routinely gathering information and data such as: river level and flow, runoff, groundwater level, precipitation, evapotranspiration, temperature, wind speed, solar radiation, air humidity, biological indicators etc.

The challenge faced in Georgia is to accurately estimate the water balance of a river basin in absence of proper coverage of the monitoring systems for collection of hydrological data since the collapse of the Soviet Union.

This report will present different methodologies that have been adopted in various countries with different level of technological capacities to collect data. The first conclusion is that there is no easy way to go around the

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[1] Guidance document 34 on the application of water balances for supporting the implementation of the Water Framework Directive (WFD)

lack of data, and approaches are mostly very rigorous, requiring at least a year of data collection before being able to compiling any significant information.

Reliability of water balance estimates will depend on conceptual model development as well as performance of a site specific model. Thus the accuracy of a water balance calculation is quite important because the licensing/permitting strategy might depend on it. This strategy can vary from catchment to catchment due to the need to manage local features and issues, or account for better, local information.

When an appropriate monitoring system is in place, the water balance also helps understanding which parts of the catchments, due to existing abstractions, may not have enough water to support the river ecology. In the case of Georgia and the Aragvi River in particular, before the new Draft Water Law brings back surface water abstraction permits, further investigations are required on water abstraction licenses and permits that may be causing or have the potential to cause environmental damages. With an accurate water balance, the responsible authority should be in the position to consider, based on the evidence of the findings, to vary or revoke the water abstraction licenses and permits.

2 REVIEW OF BEST PRACTICES ON MOST COMMON METHODOLOGIES FOR CALCULATION AND FORECAST OF WATER BALANCE AT RIVER BASIN LEVEL.

This section presents some of the best practices adopted around the world for calculation and forecast of water balance at the river basin level, from high to low-tech solutions, starting with the European Union (EU) initiatives that may be important to keep as a reference, given the approximation process that Georgia is pursuing towards the EU.

2.1 THE GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS (GEOSS)[2]

EU Member States' ability to control and allocate their own resources is undermined by illegal abstraction. Satellite mapping of river basins offers new opportunities for putting an end to the waste of water. The Global Monitoring for Environment and Security program (GMES/COPERNICUS) helps Member States to identify irrigated zones that fail to match legal water-use permits. Europe is an active partner in building the Global Earth Observation System of Systems (GEOSS), which gathers and shares comprehensive, long-term observation data on the water cycle, including precipitation, snow cover, evaporation/evapotranspiration and water use, permitting better management of resources. The Global Earth Observation System of Systems (GEOSS) is being built by the Group on Earth Observations (GEO) on the basis of a 10-Year Implementation Plan running from 2005 to 2015. GEOSS seeks to connect the producers of environmental data and decision-support tools with the end users of these products, with the aim of enhancing the relevance of Earth observations to global issues. The result is to be a global public infrastructure that generates comprehensive, near-real-time environmental data, information and analyses for a wide range of users.

In order to benefit from the GMES program, the hydro-meteorological monitoring system of Georgia needs to be strengthened to produce a sufficient amount of data that would allow the GEOSS to fulfill its potential.

2.2 THE ENVIRONMENT AGENCY (EA) OF THE UNITED KINGDOM (UK) [3]

The EA of the UK accurately monitors the environment and existing abstraction in order to understand the water balance of their catchments and what water may be available for future use through Catchment Abstraction Management Strategies (CAMS). They publish their results in their Abstraction Licensing Strategies.

Each UK water company is required to have a Water Resources Management Plan (WRMP). These plans show how water companies are going to manage the supply and demand for water over a 25-year period.

The EA uses information from the monitoring network to assess the current and past water and ecological situation. At the start of the resource assessment they calculate a water balance for each catchment.

The EA methodology represents the most traditional one, based on an extensive network of hydrological and meteorological stations that supply information about the water resources of a specific area and cross check those data with permits, licenses and the information provided by the WRMPs of license holders.

2.3 WATER BALANCE CALCULATION FOR THE DEAD SEA THROUGH IMPROVED COMPUTER SIMULATIONS[4]

An international team of researchers calculated the water flows around the Dead Sea, concluding that the drinking water resources on the eastern, Jordanian side of the Dead Sea could decline more severely as a result of climate change than those on the western, Israeli and Palestinian side. Even now, the available

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[2] http://www.copernicus.eu/
[3] https://www.gov.uk/government/organisations/environment-agency
[4] http://www.ufz.de/index.php?en=33033

groundwater resources in the region are not sufficient to meet the growing water requirements of the population and agriculture and the situation is a useful example for some of the river basin in Georgia where, if the situation worsens, could have serious social, economic and ecological consequences for the region.

A reliable inventory of existing water resources around the Dead Sea forms the basis for sustainable water management. For a long time, the complex hydrology of this region presented major unknown factors in the local water balance equation, and to some extent, it still does. Thanks to **improved computer simulations**, the researchers were able to estimate how much water actually infiltrates from rainfall and replenishes the groundwater reservoir, estimating the maximum withdrawal limit for the resource to be managed sustainably.

A combination of comprehensive on-site measurements, remote sensing and computer modelling systems were necessary to be able to provide a fairly reliable information. The springs in and around the Dead Sea were identified using infra-red sensors on aircraft and satellites, as well as chemical and isotopic methods. By analyzing rare earth elements they were able to trace the origin of the water and the routes it takes underground. Together with colleagues from the Max Planck Institute in Bremen, they identified the biogeochemical processes that make permanent changes to the groundwater.

Using models, the scientists were able to make predictions about possible future changes in the groundwater resources that are vital for the region.

2.4 WATER BALANCE OF TONLE SAP LAKE OF CAMBODIA[5]

The Tonle Sap Lake of Cambodia is the largest freshwater body of Southeast Asia, forming an important part of the Mekong River system. A detailed water balance model was developed based on observed data of discharges from the lake's tributaries, discharge between Mekong and the lake through the Tonle Sap River, precipitation, and evaporation. The overland flow between the Mekong and lake was modelled with the EIA 3D[6] hydrodynamic model.

As per the Aragvi River Basin, the Mekong is facing rapid development, including deforestation, large irrigation schemes, and construction of hydropower dams with large reservoirs. Recent hydrological impact assessment studies conclude that due to the planned development, the dry season water levels would rise, and wet season water levels would become lower, relative to current conditions.

The knowledge of the hydrology of the Tonle Sap system and its hydrodynamic relationships with the Mekong mainstream has increased rapidly during the last years. **There are still, however, information gaps.** Sufficient data have not been available for all the water balance components of the lake, most particularly discharge and volumetric flow data – largely the result of the complexity of the regional relationships of water level, discharge, and flow direction. The whole picture of the lake water balance is still missing.

To examine the relative magnitude and timing of each of the flows entering and leaving the lake, the study developed a water balance model for the lake–floodplain system.

The water balance was computed at a daily time step over eight years, for the period May/1997–April/2005. The model does not include the interaction of groundwater and floodplain due to the absence of detailed data of these processes from the floodplain. The hydrodynamic model applied to the lake does not have a groundwater component that could be coupled with the flood modelling, and thus enable simulation of flood–groundwater interconnections.

A Data-Based Mechanistic (DBM) model of the lake and its floodplain was derived from three spatial data sets: **(1) a hydrographic survey** (Mekong River Commission, 1999) was used to compute the contours for the dry season lake area and Tonle Sap River; **(2) the Certeza survey map** (1964) was used for the Tonle Sap Floodplain; and **(3) the Shuttle Radar Topography Mission data** (Farr et al., 2007) was used for the surrounding areas to complete the DBM. Geographic Information System (GIS) datasets used for mapping and flood analyses, included river, lake and inundated area layers, the Tonle Sap Basin sub-catchments, and the locations of hydrological measurement stations. The DBM was used to calculate the daily lake area and lake volume as a function of water level in Kampong Luong.

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[5] http://www.researchgate.net/publication/235936064_Water_balance_analysis_for_the_Tonle_Sap_Lakefloodplain_system

[6] EIA 3d model is a three-dimensional numerical finite difference hydrodynamic model, than can be used to model surface waters such as lakes, rivers, floodplains and coastal areas http://www.eia.fi/?q=node/12

The DBM was also used for the flooded area calculations for each catchment. The relationships between water level, inundated area, and volume were calculated using the DBM of the lake and its flood plain. The open water area and volume of the lake varies as a direct function of water level.

2.5 MASSACHUSETTS: USE OF GIS FOR WATER BALANCE CALCULATION[7]

The water balance tool developed for the Taunton River Watershed Study is a planning level assessment designed to evaluate the hydrologic impacts associated with water supply withdrawals, wastewater discharges and storm water runoff associated with land uses. The method uses a mass balance approach that accounts for net changes in groundwater recharge as it relates to base flow to streams and wetlands on an annual basis. It estimates stream-based flow changes resulting from water withdrawal, water transfer, wastewater discharges and storm water runoff associated with different land uses. Base flow is the flow that sustains the stream between precipitation and runoff events. It is derived from discharge from groundwater and from surface water storage released from wetlands and impoundments. Base flow is the stream flow that continues after runoff from precipitation has ceased for several days. The tool is intended primarily for comparative purposes between and among sub-watersheds. Different sub-watersheds of the Taunton River watershed can be compared against each other in terms of their relative degree of water balance impairment. This information serves as a mean to target sub-watersheds in greatest need of remedial activities and to evaluate the water balance impacts of potential land use management options. This water balance tool calculates both pre-development (natural), and post development recharge. It also provides a tool to evaluate future land use scenarios and the associated water, sewer and storm water infrastructure impacts. The Massachusetts Department of Environmental Protection (DEP) and the Executive Office of the Energy and Environmental Affairs (EOEEA) have developed policies to “keep water local” by maintaining a balance between water withdrawal and discharges[8].

The US Geological Survey (USGS) started collecting real-time stream flow data for the Rattlesnake Brook near Assonet (USGS station 01109090) in January 2007. As a result, a full year of daily mean flow January 1, 2007 - December 31, 2007 was reviewed for the USGS gauge station.

Given that only one full year of data had been collected, statistical flows were not available for the stream. An average annual base flow for Rattlesnake was estimated by comparing its measured flows to long term data obtained for another Massachusetts reference stream that is geographically close to Rattlesnake, and has similar watershed characteristics.

Impervious and pervious surfaces were identified throughout the watershed using an Office of Geographic Information (MassGIS) image shapefile that displays all of the impervious areas throughout the state. Impervious surfaces include rooftops, roads, parking lots, and incidental impermeable surfaces such as sidewalks, patios, pools, etc. the Total Impervious Area (TIA).

GIS was used to estimate areas serviced by public wastewater and water systems. Sewer and water line data provided by DEP and communities in the watershed was used as a basis for estimating the service areas (Section 2)

2.6 A WATER RESOURCES PLANNING TOOL FOR THE JORDAN RIVER BASIN - USING WATER EVALUATION AND PLANNING (WEAP)

WEAP is a Windows-based decision support system for integrated water resources management and policy analysis. WEAP is a model-building tool, used to create simulations of water demand, supply, runoff, evapotranspiration, infiltration, crop irrigation requirements, instream flow requirements, ecosystem services, groundwater and surface storage, reservoir operations, and pollution generation, treatment, discharge and instream water quality, all under scenarios of varying policy, hydrology, climate, land use, technology and socio-economic factors. It can be dynamically linked to the USGS MODFLOW groundwater flow model and the US EPA QUAL2K surface water quality model.

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[7] http://www.horsleywitten.com/tauntonwatershed/Documents/Final%20Report/Section%204%20Water%20Budget.pdf
[8] http://mass.gov/dep/water/local.htm

In “A Water Resources Planning Tool for the Jordan River Basin” (Holger Hoff, Christopher Bonzi, Brian Joyce and Katja Tielbörger, 2011[9]) the authors developed with stakeholders a dynamic consensus database and a basin-wide WEAP tool for the Jordan river, which allowed testing of various unilateral an multilateral adaptation options under climate and socio-economic change. They compiled data from various national sources representative of historical conditions from the recent past (figure 2, pg. 723). Some of the discharge data for the larger tributaries dated back as far as 1970. These data were used to construct a baseline scenario that represented to date water management conditions.

Whenever the full historical period could not be obtained, data was taken from shorter time series (e.g., for some eastern side wadis[10] data was only available for the period 1990–2005), or from nearest data series (e.g., for some demand nodes data was only available for the time period 2002–2007).

The limit of WEAP, despite its great features, is the same for every modeling software though: “garbage in-garbage out”. If data are not accurate, the result will reflect the poor accuracy of the input.

[9] www.mdpi.com/2073-4441/3/3/718/pdf
[10] Valleys, ravines, or channels that are dry except in the rainy season.

3 WATER BALANCE WITH REMOTE SENSING

Water balance calculation with remote sensing technology is particularly developed in India.

India has the largest constellation of Remote Sensing Satellites, which provide services both at the national and global levels. From the Indian Remote Sensing (IRS) Satellites, data is available in a variety of spatial resolutions starting from 360 meters and highest resolution being 2.5 meters.

Imagery sent by IRS spacecraft is used for a variety of purposes with agricultural crop acreage and yield estimation being among the most important ones. Such imagery is also being used for ground and surface water harvesting, monitoring of reservoirs and irrigation command areas to optimize water use. Forest survey and management and wasteland identification and recovery are other allied uses. This apart, IRS imagery is also used for mineral prospecting and forecasting of potential fishing zones.

With regard to applications in planning and management, IRS data is being used for urban planning, flood prone area identification and the consequent suggestions for mitigation measures. Based on this experience, the concept of Integrated Mission for Sustainable Development has been evolved wherein the spacecraft image data is integrated with the socio-economic data obtained from conventional sources to achieve sustainable development.

A few examples of remote sensing application to water resources management are described here below.

3.1 REMOTE SENSING AND GIS APPROACH FOR ASSESSMENT OF THE WATER BALANCE OF A WATERSHED[11]

For this study, the water balance was obtained using the Thornthwaite and Mather (TM) model with the help of remote sensing and GIS to help finding out the periods of moisture deficit and moisture surplus for the entire basin. The base map of the study area was prepared using Survey of India SOI[12] topo sheet no. 53J/10 SW on a scale of 1:25 000. Remote sensing data of IRS-1D LISS-III and Panchromatic (PAN) sensor data of the study area were downloaded by [73.128.183.91] at 07:30 16 October 2015.

The satellite data was first rectified, corrected and georeferenced to the Universal Transverse Mercator (UTM) projection system. Digital image-processing techniques were applied on the image, making use of various image enhancement techniques in order to bring out the desired information. Then the watershed boundary and drainage network of the study area was delineated and digitized using the SOI toposheet and satellite imagery. A field visit was made in order to collect the training sets for preparation of a land-use/land-cover map of the study area. During the field visit, actual ground conditions were verified and training sets for different land uses were marked. Seven different land-use/land-cover features were identified using supervised classification. Earth Resources Data Analysis System (ERDAS) IMAGINE 8.5 software was used for digital image processing operations such as image rectification and classification (ERDAS, 2001). The relative area under different land-use features reads: dense pine forest 42%, agricultural land 32%, oak and pine forest 14%, barren land 5%, open forest 4%, settlement 2%, river 1%. A soil texture map of the study area was prepared using a soil map of India (National Bureau of Soil Survey and Land Use Planning (NBSS) and Land Use Planning (LUP) Nagpur, India) and a limited field check. The mean monthly precipitation and observed runoff for the period February 1986–January 1987 were taken from the work done by Rawat & Rawat (1994). The temperature of the area was obtained from the nearest meteorological station, which was 12 km away from the study area.

As a conclusion, the water balance study using the TM model with the help of remote sensing and GIS was shown to be very helpful in finding out the periods of moisture deficit and moisture surplus for an entire watershed.

Such studies can be very beneficial for the local farmers who can decide their crop calendar and irrigation requirements based upon the periods of deficit or surplus. Water conservation measures can also be planned well in advance based upon the duration of deficit and surplus.

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[11] http://www.tandfonline.com/doi/pdf/10.1623/hysj.49.1.131.53997
[12] Survey of India

3.2 IMPLEMENTATION OF A MEAN ANNUAL WATER BALANCE MODEL WITH A GIS FRAMEWORK[13]

The implementation of a mean annual water balance model with a GIS framework demonstrates how a simple water balance model can be used in a GIS framework to estimate the impacts of vegetation changes on mean average catchment water yield. The Zhang et al. (2001) simple water balance model considers the effects of available energy and water on evapotranspiration and requires only mean annual rainfall and vegetation cover. To facilitate practical application to large catchments, the model was implemented in a GIS environment, which enables spatial analysis of rainfall and vegetation data, and eventually catchment water yield. Procedures involved in the spatial data handling are explained in detail in the report (see Appendix B of the Report on Implementation of a Meaan Annual Water Balance Model With a GIS Framework and Application to the Murray Darling Basin)[14].

Comparison between predicted and measured water yield under current land use conditions showed that predicted yields from the model were reasonable forecasts for catchments with high rainfall. However, the model tended to overestimate water yield for low rainfall catchments.

This study also attempted to evaluate the impact of afforestation on future catchment water yields.

For this study, monthly-interpolated rainfall surfaces were combined to give mean annual rainfall surface for a period of 15 years. The grid point analysis technique used to derive surfaces provides an objective average for each grid cell and provides useful estimates of rainfall in data-sparse areas. In the case of Georgia, this methodology should be applied at national scale to be able to derive average of precipitations for each catchment.

3.3 INDIA: REMOTE SENSING DATA AND GIS[15]

Remote sensing is probably one of few techniques which can provide representative measurements of several relevant physical parameters at scales from a point to a continent. Methods using remote sensing information to estimate heat exchange between the land surface and atmosphere can be broadly put into two categories: to calculate the sensible heat flux first and then to obtain the latent heat flux as the residual of the energy balance equation, or to estimate the relative evaporation by means of an index using a combination equation.

This study explains in detail a methodology to estimate the hydrologic water balance components from available online sources. The results have been proven to be quite close to the real measures, according to the authors. This methodology would require most likely support from a university with highly skilled hydrologist and GIS experts.

3.4 INDIA: GIS BASED SIMPLIFIED WATER BALANCE16

This study describes the implementation of a simple water balance model in a GIS framework for calculating annual water balance of Koyna (Upper Krishna) Basin in India. The models require only catchments percentage forest cover and mean annual rainfall. The study utilizes average mean rainfall data, estimated mean annual catchments and vegetation cover data under different land use conditions for the basin. The model tended to overestimate water yield for low rainfall catchments.

The grid-based hydrological model is a digital hydrological model, which provides a solid foundation and powerful technical supports to apply remotely-sensed rainfall data to hydrological models. Radar-or-satellite-captured precipitation data have an advantage of high spatial and temporal resolutions. Such an advantage may be fully and completely utilized in the grid-based hydrological model. With a closed combination of remotely sensed precipitation data and rainfall-runoff models, the puzzling rainfall input problem in hydrological models can be overcome. Consequently, it will be of great benefit to enhance flood forecast accuracy and forecast period.

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[13] http://www.fao.org/forestry/42679-06c5b4f34ca7eb9155af198cbfdf42498.pdf

[14] Implementation of a Mean Annual Water Balance Model Within a GIS Framework and Application to the Murray-Darling Basin - paragraph 2. GIS Framework for the Water Balance Model and Appendix 2 (http://ewater.org.au/archive/crcch/archive/pubs/pdfs/technical200108.pdf)

[15] http://www.researchgate.net/publication/225146802_Water_Balance_Study_for_a_Basin_Integrating_Remote_Sensing_Data_and_GIS

[16] http://www.eng.warwick.ac.uk/ircsa/pdf/12th/6/Dashrath-KB.pdf

4 WATER DEMAND FORECASTING[17]

The history of predicting water use and related economic activity, population growth, and other variables of importance to water and economic planners shows that precise predictions are very difficult. Nevertheless, the capacity to anticipate and affect future water demand paths is pivotal for a government to be able to ensure sustainable management of the resource and economic growth. Water demand disaggregated by sector and geographic area, and estimated over different time lapses, is being recognized as an important tool in managing water resources at national and local level. Water managers need to understand spatial and temporal patterns of future water use in order to optimize system operations, plan for future water purchases or system expansion, or for future revenue and expenditures.

There are several mathematical methods in use for estimating future demand; these include extrapolating historic trends, correlating demand with socio-economic variables, or more detailed simulation modeling.

Models vary in complexity according to the number of variables and the extent to which water users are disaggregated by sector, location, season, or other factors. Models also vary according to the forecast horizon. Long-term forecasting is typically more useful for infrastructure and capital planning whereas short-term forecasts are more useful for setting water rates.

Data can be classified into three broad categories: water usage, water demand drivers, and water demand factors. Water usage is defined as the amount of water used for a particular purpose during a specific amount of time. Water demand drivers are defined as "countable units driving water demands" such as number of households, acres irrigated, employees, etc." Water demand factors are variables that are known to influence water demand, such as weather, income, type of commercial/industrial activities, crop type.

For the public-supplied residential sector, the basic methodology developed for estimating future demands for each catchment is the average residential water use per capita times the projected population served within the catchment.

Data is needed to estimate current and future water population serviced by water systems, the average per capita residential rate of use, and the percent of water lost during water production and transmission.

More detailed models may take into account a wide variety of factors, such as changes to population, water prices (e.g., price elasticity); the climate (e.g., weather variability is appropriate for short-term forecasts while global climate models are useful for longer-term forecasts); users behavior (e.g., increased use but also increase attention to conservation and efficiency); new regulations, economic and industrial development.

Closely related to the public-supply residential forecast is the public-supply nonresidential forecast.

Nonresidential water use is estimated by multiplying employment rate by water use per employee.

Water managers use demand forecasting in a variety of ways, but among the most important ones is for water rates. Water service providers want to anticipate how much water they expect to sell in order to ensure that revenue will cover costs.

Several programs exist to help predicting the effects of conservation programs on demand.

Most demand forecasting models are deterministic and show a single estimate of future consumption. Probabilistic models, by contrast, produce a range of outputs rather than a single output. Even with deterministic models, a sensitivity analysis can help understand how the uncertainty in input parameters affects demand estimates. For example, instead of calculating a single forecast using a population growth rate of 1% per year, the analyst may run the model several times, with growth rates varying from 0.5% to 1.5%. Such an analysis demonstrates the sensitivity of the model, or how the result changes in response to this one variable. These methods are especially useful where a parameter is highly uncertain or a range of possible values are equally likely (for instance, when projecting future growth).

[17] https://www.owrb.ok.gov/supply/ocwp/pdf_ocwp/WaterPlanUpdate/WaterDemandForecastReport.pdf

5 APPROPRIATE METHODOLOGY FOR THE CONTEXT OF GEORGIA

The methodologies illustrated above give an idea of the variety of solutions that can be adopted to research and improve the accuracy of the estimation of the water balance for the Aragvi River and to forecast the trends.

Each of these methodologies had to be adapted to the context, and expert hydrologists were at work for a prolonged period of time before being able to collect the necessary amount of data required to accurately estimate and predict the water balance for a specific catchment.

5.1 THE INDIAN WAY

Given the situation of Georgia, where hydro-meteorological data is not easily available and is mostly from the Soviet time, the adaptation of a GIS methodology with Remote Sensing data could be considered as the most appropriate.

Data can be acquired from the National Remote Sensing Centre Indian Space Research Organization that has a page dedicated to Foreign Satellite Data[18]. Prices seem to be quite reasonable, although the total cost can only be estimated by submitting a specific request.

This methodology will require most likely a team of at least 2: one GIS expert and one hydrologist with previous experience with GIS water modeling. The support of a university with the relevant technical capabilities may be sought instead, although the project team may risk to lose control on the period of performance in this case.

To build capacity at national level, Georgia could consider to pursue an agreement with the Indian Institute of Remote Sensing (IIRS) set up for developing trained professionals in the field of Remote Sensing, Geoinformatics and Global Positioning System (GPS) Technology for Natural Resources, Environmental and Disaster Management[19]. The reasons to look at opportunities with Indian institutions are at least two:

- They are technically and technologically advanced;
- They operate in a context similar to Georgia, where hydro-meteorological information is not always available or up to date; hence they developed particular capacities with indirect monitoring systems of their natural resources.

5.2 THE ITALIAN APPROACH

The alternative to the Indian approach could be to partner with the Laboratory of Geomatics and Earth Observation[20] that includes, among others, research groups from the Departments of Civil and Environmental Engineering (DICA), Built Environment and Construction Engineering (DABC) and the Department of Aerospace Science and Technology (DAER).

The Laboratory is leader in open source Geomatics and Earth Observation systems and related GIS software for data analysis and representation.

The researchers of the Laboratory deal with the analysis of classic and satellite geodetic observations, their filing and the management of geographical information systems, including web-shared ones, and with the design of systems/missions that can support the generation of satellite data related to Earth observation.

The Laboratory can help designing and creating territorial information systems for the management of georeferenced data (including via the web). The Laboratory also collaborates with the group of Aerospace Science and Technology to define the methods and time required to acquire observations based on the information that has to be collected.

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[18] http://www.nrsc.gov.in/Data_Products_Services_Satellite_Foreign.html
[19] http://www.iirs.gov.in/
[20] http://www.polimi.it/en/scientific-research/research-structures/interdepartmental-laboratories/geolab-geomatics-and-earth-observation-laboratory/

A cooperation agreement for knowledge and technology transfer could be sought with the Politecnico of Milan. The advantage of working with a European institution would certainly help with the approximation process of Georgia to the European standards.

6 OTHER RESOURCES FOR MORE CASE STUDIES AND BEST PRACTICES:

Handbook for the Assessment of Catchment Water Demand and Use (DfID)

http://www.samsamwater.com/library/handbook_catchment_water.pdf

The IIMI Water Balance Framework: A Model for Project Level Analysis

http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/pub005/REPORT05.PDF

IWA best practices for water balance

http://www.leakssuite.com/concepts/iwa-water-balance/

http://www.mcast.edu.mt/Portals/0/IAS%20Lib/IWA%20April%202014-%20Water%20Benchmarking.pdf

FAO: Water accounting and auditing: Understanding the water balance

http://www.fao.org/nr/water/docs/WSRE_wateraccounting.pdf

Water Resources Planning Under Uncertainties

http://environ.chemeng.ntua.gr/WSM/Uploads/Deliverables/ThirdYear/Deliverable_21_3.pdf

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