Chapter 12
Water Management Priorities for Sustainable Socio-economic Development

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Abstract This chapter presents real-time water management system operation practices that can be partially adopted for use in Ethiopia with some adaptations to suit realities in the country. State-of-the-art concepts, methods, and procedures based on current practices in the USA, South Florida Water Management District (SFWMD), are illustrated. The historical evolution of the South Florida Water Management System is described. The current state of water management is explained to provide ideas of what can be used in Ethiopia. Objectives of water management in Ethiopia and USA can be similar. The question is if opportunities exist to utilize information on advances in water management concepts, methods, and processes. It is important to identify practices in the developed world that can be adapted to the needs and realities of developing countries. In most countries, water management evolves through similar stages. The initial stages of socioeconomic development result in undesirable consequences such as deforestation, soil erosion, and ecological degradation. When unintended adverse consequences become apparent, societies wake up to nature's call for help. Historically, South Florida was swampy land. From the late nineteenth to the mid-twentieth centuries, Florida swamps were drained to make land available for agriculture and industrial development. Cities were built and agriculture expanded on drained land. Transportation and other industrial infrastructure substantially replaced natural wetlands. Such endeavors were followed by undesirable environmental outcomes including degradation of natural habitat, floods accompanied by loss of human and animal life, as well as recurrent water shortages. In the late 1940s and 1950s, national efforts were geared toward flood control, water supply, and navigation. In the 1970s and subsequent decades, water management policy centered around water quality and ecology stressing the idea of fishable and swimmable rivers. The current water management practice in the USA focusses on ecosystem restoration while continuing to meet other goals including flood control, water supply, navigation, and recreation. Within the context of water management in Ethiopia, the recommendation is to learn from experiences of nations ahead in the water management evolution and to minimize adverse environmental outcomes. Ethiopia can adopt and

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enhance integrated water management with a clear focus on food, ecology, energy, and related development endeavors while promoting mitigation of undesirable environmental consequences.

Keywords Real-time water management · Remote operation · Alternative renewable energy · Water management policy · Flood control · Irrigation · Hydropower · Environmental degradation · Ecosystem restoration

Introduction

This chapter presents water management practices Ethiopia can adopt based on current applications in the USA, particularly in the South Florida Water Management District (SFWMD). SFWMD has flood control, water supply, water quality, and natural systems management responsibilities over 16 counties extending from Orlando to the Florida Keys (Fig. 12.1). For the purpose, SFWMD uses various tools and processes in concert to fulfill the needs of data acquisition, transmission, display, processing, and archival. Extensive infrastructure is in place that enables daily water routing strategies and helps achieve defined goals at high levels of effectiveness. Water control stations, associated weather stations, remote data collection units, and communication loops and lines constitute the infrastructure enabling real-time operation of such a large-scale water management system remotely.

Background

Information Infrastructure

The Supervisory Control and Data Acquisition (SCADA) system links various functions and devices between remote field sites and the Operation Control Center (OCC). Typically, the linkage is between the remote data acquisition device, the telemetry transmission network, and data receiving servers, display terminals, and archival databases (Fig. 12.2). The other function of the SCADA system is transmitting operational commands from OCC to remote sites. Commands include opening and closing gates, starting and stopping pumps, and raising and lowering weirs. Commands initiated in OCC are implemented at remote sites spread out over hundreds of miles (Imru and Damisse 2004). Water management decisions are made remotely or in some cases message is passed to onsite staff operating structures or large pump stations.

Data acquired from remote sites get processed and archived in servers in SFWMD headquarters. The process of data acquisition, verification, and archival triggers automatic discharge computation using a software application called

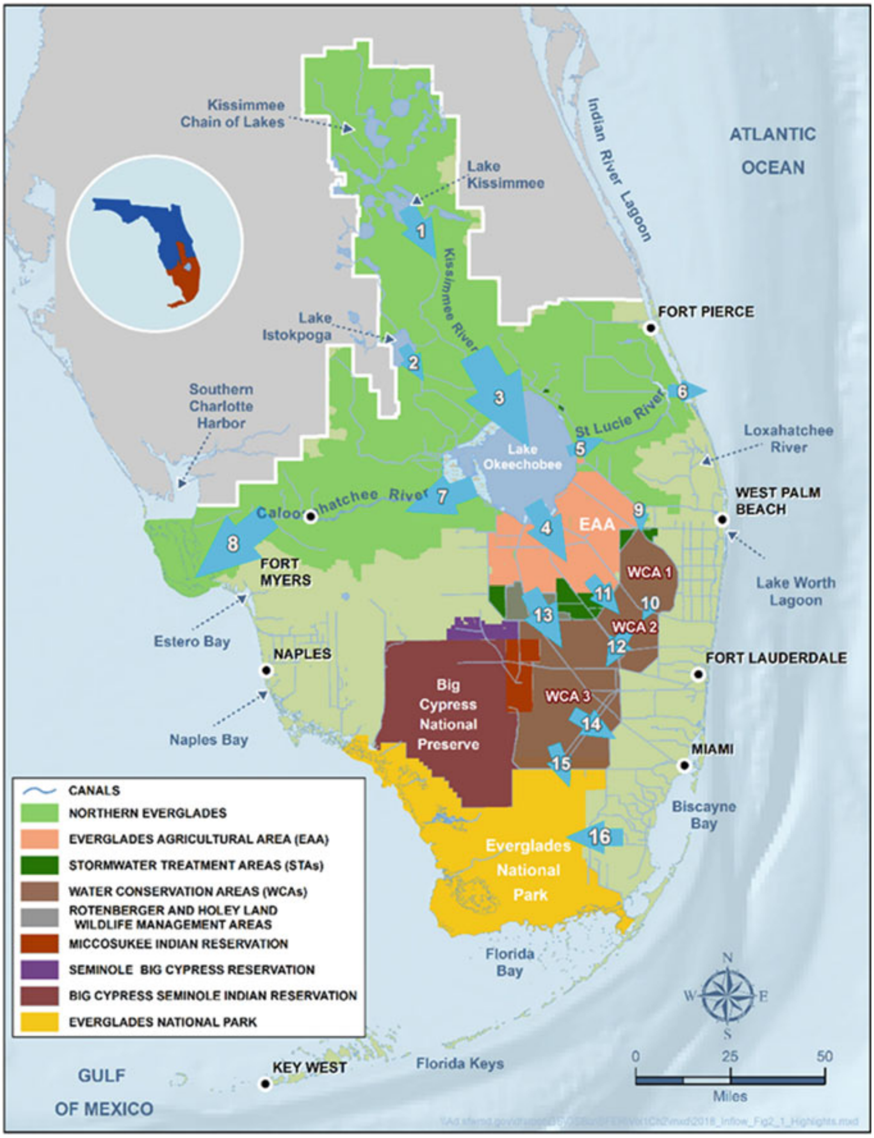


Fig. 12.1 South Florida water management district and major features (South Florida Water Management District 2018)

FLOW that is embedded in the system. FLOW is linked to the corporate hydrometeorological database called DBHYDRO, which is configured to provide static parameters such as structure dimensions and discharge coefficients as needed. Data acquisition, display, and flow calculation can happen in real time. For water management operations, hydrodynamic data available in real time include

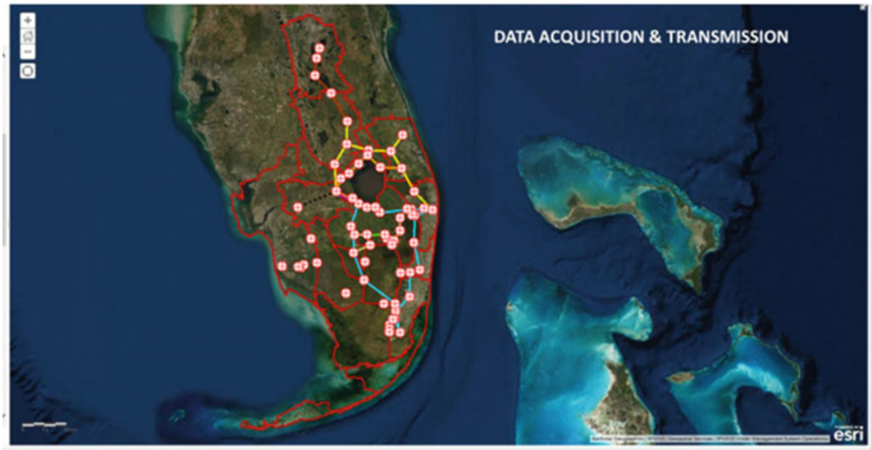


Fig. 12.2 Data acquisition and transmission infrastructure

headwater stage (HW), tailwater stage (TW), and discharge (Q) among others. The quality assurance process takes time, which means using quality-checked data for discharge calculation and archival happens over a period longer than what would be considered near real time. Real-time and historical data are used for system operation as well as project planning and management.

Operation

The hydrologic cycle dictates the natural variability of water flow at any location. Water can be excess or short depending on weather conditions. Human intervention helps to balance between excess availability and shortage of water. Management of spatial and temporal variation of water availability serves various purposes.

During wet conditions, the system is operated for flood control. For flood control, canal stages are maintained lower than normal, lakes and reservoirs are lowered to increase available storage capacity, and water is discharged downstream. During dry conditions, the system is operated for water conservation. Only water needed for downstream use is released while attempts are geared toward conserving fresh water as far upstream as possible. When conditions are dry, stages of lakes, reservoirs, canals, and wetlands are maintained high while trying to provide water supply downstream for agriculture, urban, and ecosystem needs. Efforts are made to keep fresh water inland, maintaining stages higher than the ocean surface water level, always to recharge ground water and protect against saltwater intrusion. Protecting freshwater inland is a critical need. Figure 12.3 shows lakes, shallow reservoirs, and constructed wetlands in the central region of the water management system.

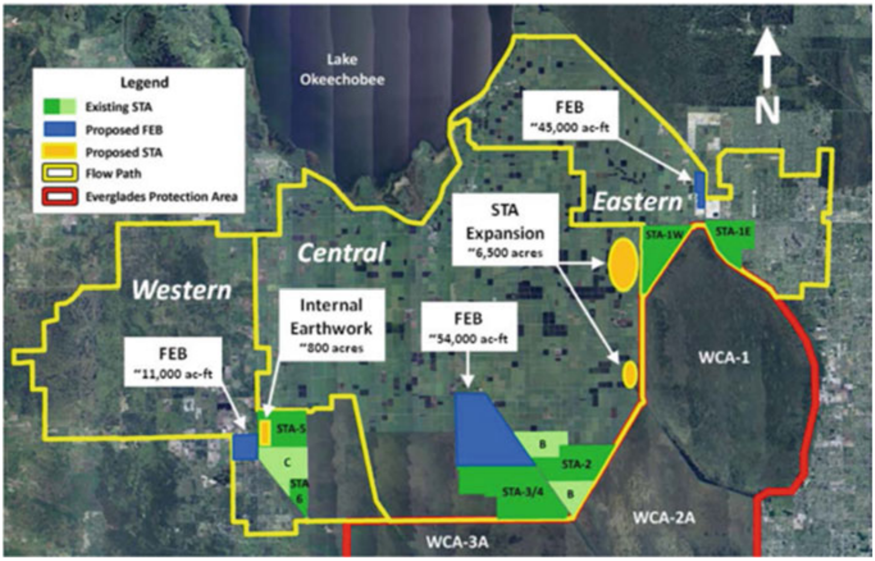


Fig. 12.3 Regional water control infrastructure (central area—partial)

The idea of keeping as much water as far upstream as possible could be considered a particularly good concept for Ethiopia using any means available in the country. Lakes like Tana can be maintained high using a suitable regulation schedule. A regulation schedule could help keep the lake high enough to store extra water for drier times, while simultaneously low enough to keep the beautiful city, Bahr Dar, dry and convenient for its residents and visitors. Water can then be released for groundwater recharge, ecosystem enhancement (in the form of afforestation and soil conservation), agriculture, and urban water use. Results of effective water management include food production in excess of local consumption, well-maintained ecosystem, abundant and healthy marine and other wildlife, adequate urban water supply, and minimized risks of flooding and drought. These attributes account for most of Florida's appeal to residents and visitors. Efficient water management utilizes concepts, processes, and tools effectively in conjunction with environmental data.

In south Florida's case, remote access to instantaneous data has enabled real-time remote operation. This is made possible with the help of the Operation Decision Support System at the OCC where real-time weather conditions and system hydraulic state are displayed on multiple monitors to a 24-h monitoring staff (Fig. 12.4). Decisions are executed mostly via the OCC workstations shown in the figure, while in some cases the decisions are communicated to field staff in remote locations for execution onsite.

Environmental data collection is done at various stations distributed throughout the region. There are large numbers of stations for collecting data on weather, surface and ground water stage, water quality, and ecology. Data from the extensive

Fig. 12.4 South Florida water management district operation decision support system (Sylvester 2015)

network of stations are archived in various specialized databases. Data from weather stations include rainfall, wind speed, temperature, humidity, and solar radiation. Most stage and water quality data collection devices are installed in conjunction with water control sites. Ecological data are generally related to water management areas. Ecological data include vegetation, fish, and wildlife. Water quality is a major aspect of environmental monitoring for the purpose of regulating and managing nutrients and other pollutants. One of the nutrients of concern is phosphorus that adversely affects ecological balance in water bodies and wetlands. To reduce and control nutrients including phosphorus SFWMD uses constructed wetlands called storm water treatment areas, STAs (Fig. 12.3). Information on invasive species is collected and studied, and suitable control measures are implemented.

It is understandable that Ethiopia has hydrology and meteorology data collection networks. It is not obvious how current such information is or if there is a process in place for electronic data collection, transmission, and archival. The country needs an enhanced process for data collection and archival using interconnected, centralized as well as distributed databases. For the purpose, utilizing experiences of developed countries can help. It is likely that there is adequate technology and skill in the country. The question may be how to create a system of coordinated use of the resources for improved water management that can produce desired socio-economic outcomes like in the developed countries. The following sections describe some aspects of data use in water management to meet food production, ecosystem enhancement, and socio-economic development goals.

Hydrometeorological and Topographic Data

Water management heavily relies on hydrometeorology and topographic data. So, data acquisition, transmission, display, processing, and archival are critical functions for water management. Important data include topography, land use, rainfall, hydraulic structure (control structure) dimensions, and water surface elevation (stage) among others. Data on topography, land use, and control structure information are relatively static while water-related data are dynamic. There is variation in time scale of acquisition between various data types. Dynamic data such as water surface elevation require more frequent acquisition and transmission compared to land features or control structure information. Flow can be derived from measured data types and physical parameters of conveyance and control facilities such as canals, weirs, culverts, and pumps.

Remotely located weather stations collect meteorological data including temperature, wind speed, humidity, solar radiation, evaporation, and rainfall. The number of parameters measured varies from one station to another. Some stations have only rain gauges and measure only rainfall. Based on rain gauges, the area covered by SFWMD is divided into rain areas. Areal average rainfall amounts are recorded for each rain area based on readings from several gauges in the area. Radar rainfall estimates are also archived parallel to gauge observations.

Stage records are acquired at representative gauging stations. Water management is characterized by control of stage and discharge. In many cases, stage recorders are associated with locations where stage and discharge are controlled. Such locations have structures including gated culverts, spillways, weirs, and pumps that control stage and discharge (Fig. 12.5).

Data Transmission, Display, and Archival

The Supervisory Control and Data Acquisition (SCADA) system effects acquisition, transmission, and display of data between remote sites and central data servers and workstations. Multiple individual gauges at remote locations are connected to a nearby data polling device called remote terminal unit (RTU). From each RTU, data transmission to central servers occurs via communication loops connecting multiple telemetry towers (Fig. 12.2). The SCADA system also serves to transmit operational changes from the Operations Control Center (OCC) to remote stations where implementation of the commands is initiated and completed within minutes (Fig. 12.4). Data collected from the remote sites is stored in a corporate database, DBHYDRO and made available for public access through the web (Fig. 12.6). Figure 12.7 is an illustration of flow and stage data for a spillway.

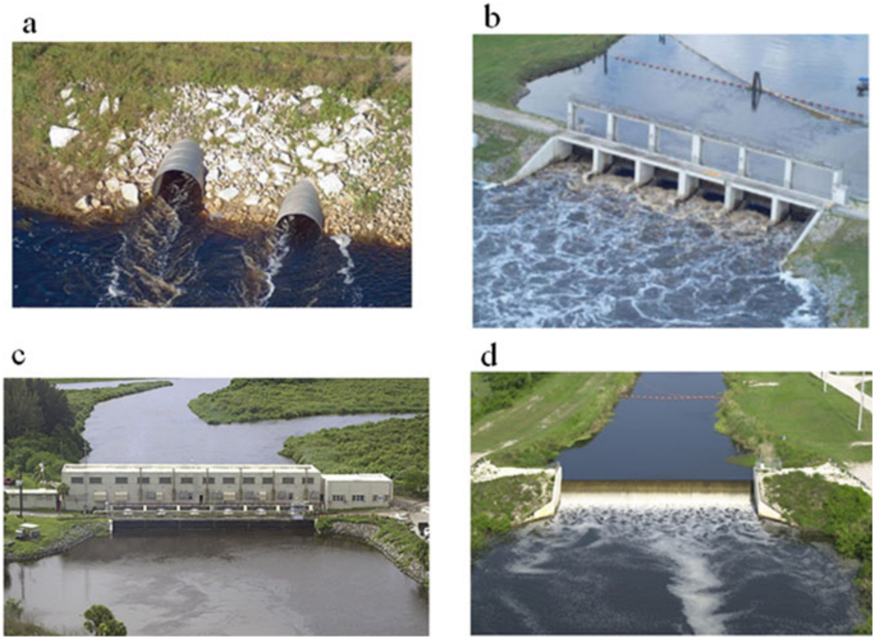
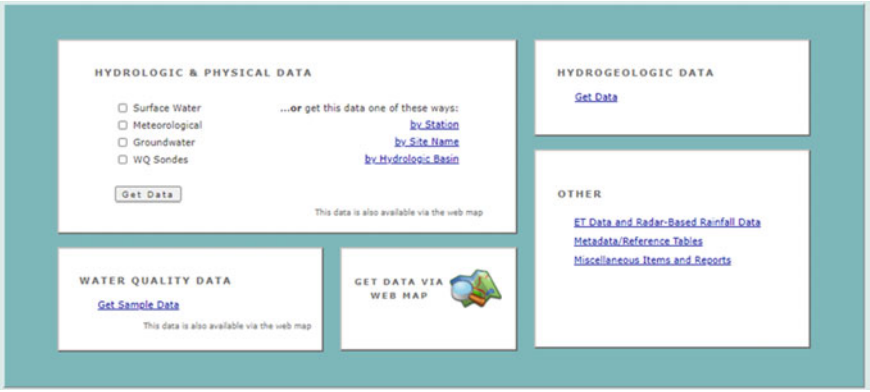


Fig. 12.5 Water control structures **a** culvert, **b** spillway, **c** pump station, and **d** weir



This data is also available via the web map

This data is also available via the web map

Fig. 12.6 Database display to extract archived data

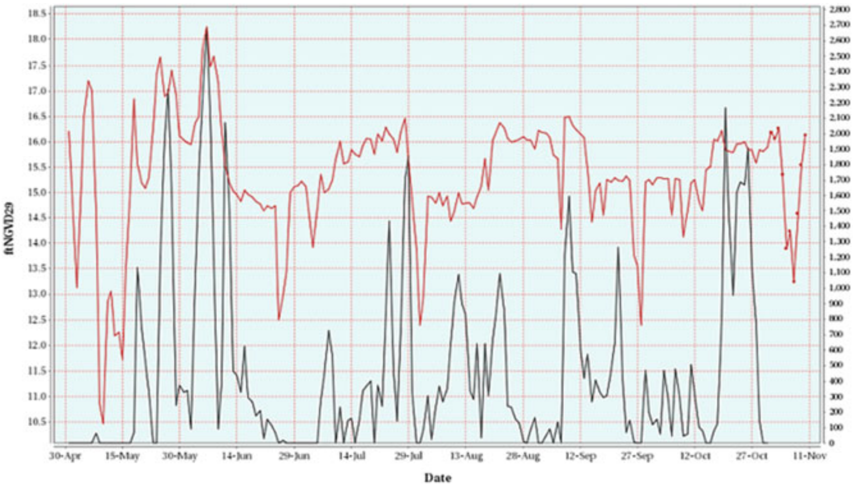


Fig. 12.7 Archive DBHYDRO database daily stage and flow data graphic display for a spillway G302

Water Management Goals

Flood Control

Flood control is a critical water management function that deals with mitigating flood risk. South Florida has a flat topography with coastal areas subject to flooding partly due to high tide. When conditions get wet and flooding is likely due to oncoming storms, operation of water control structures switches to flood control mode. Stages are reduced, in reservoirs to create storage for excess water and in canals to increase conveyance capacity. Reservoirs are operated to store water during wet conditions when there is excess and make controlled releases as needed to meet demand downstream. Preparations for flood control start before a storm arrives in an area. How far ahead the preparation starts depends on the expected intensity and area coverage of the storm. It also depends on level of automation of control structures to be engaged for the operation. If a structure is operable remotely and automated, preparation may be a few hours before the storm, whereas if local manual operation is required preparation can take from one to five days in advance depending on location and accessibility.

Water Supply

In South Florida, to meet water demand, canal stages are kept high enough for users to abstract water efficiently. When water demand is expected to rise, i.e., when conditions turn drier, water is released from reservoirs to canals to maintain stages in desired levels. Adaptive water management provides water supply for agricultural, domestic, industrial, and environmental needs. There is extensive agriculture that benefits from water availability throughout the year. Similarly, the ecology of the region is well maintained by making water of acceptable quality available when and where needed. Florida is attractive to tourists because of its weather. It is also because of its ecology, which can be substantially attributed to effective water management. It is easy to understand how water management priorities support agriculture and tourism, the backbones of Florida's economy. There is no reason, if not man-made, why Ethiopia cannot adopt effective and sustainable water management practices that can help grow its economy from its water resources.

Lake Okeechobee, with an average surface area of about 440,000 acres, is the main storage of the South Florida water management system. It serves to mitigate flooding, reserve water to meet domestic, agricultural, and environmental demands. It is operated based on a regulation schedule, various operational ranges, and guidelines for adaptability (Fig. 12.8).

Water Quality

Clean water requirements, based on human and natural system needs, define water quality standards of discharges going into freshwater bodies as stipulated in the

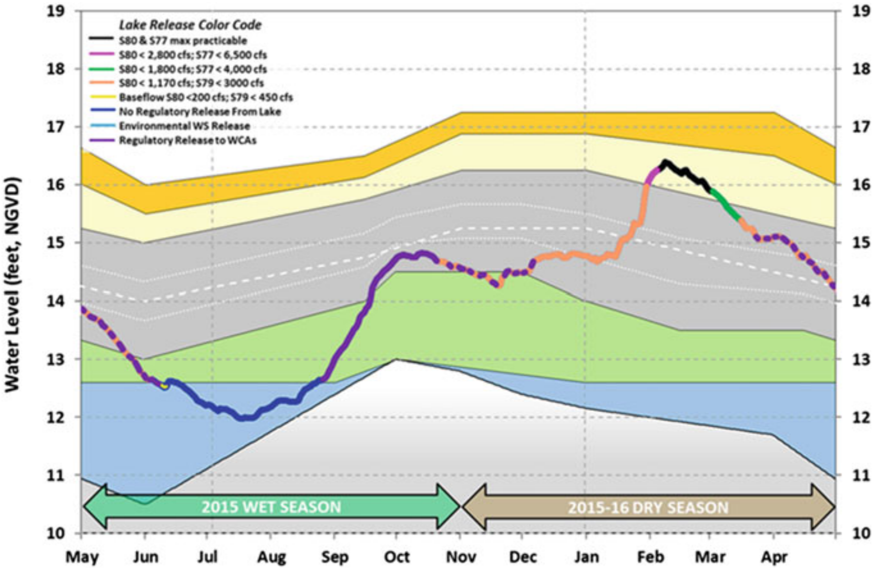


Fig. 12.8 Lake Okeechobee stage hydrograph, operation zones for water management decisions

Clean Water Act (CWA) of 1972. The Act states, “The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the USA and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972.” This is something Ethiopia can learn from, adopt, adapt to realities in the country, and implement. A similar act in Ethiopia can help reduce such grave environmental consequences as invasion of Lake Tana by water hyacinth, or unknown contamination of Rift Valley lakes due to industrial discharges from Addis Ababa, Akaki, Debre Zeit, and Nazareth.

Navigation

South Florida’s waterways are used mostly for fishing, recreation, and shorter travel for smaller boats from Gulf of Mexico in the west to the Atlantic Ocean in the east. Lake Okeechobee is a major reservoir surrounded by a dyke with gated outlet control structures discharging into major canals leading to the Atlantic Ocean on the east, to the Gulf of Mexico on the west, and to the Everglades on the south. The lake is connected to the ocean by large canals which serve many purposes including navigation. Those large canals are also used for lake stage regulation, urban and rural water supply, recharging aquifers, and protecting against saltwater intrusion among others.

Recreation

Commercial and recreational boating and fishing are widespread in Florida’s waters. Boating is regulated as is fishing like other popular activities such as hunting, driving, or aircraft flying. Regulations focus on safety and conservation of human and animal life, as well as protection of the environment. Bird watching is another popular recreational activity many people engage in. The South Florida ecosystem attracts a large variety of avian species including migratory birds. Birds and other wildlife are protected by laws established by acts of congress and bilateral agreements such as the Migratory Birds Treaty Act of 1918 and the Endangered Species Act of 1973.

Enabling Features

Water management objectives are facilitated using important features including reservoirs and lakes for storage, open channels for conveyance, pumps and gravity structures for control of flow and stage.

Lakes and Reservoirs

Storage is a crucial feature of water management. It helps to regulate spatial and temporal variations of water availability. Weather condition dictates rainfall occurrence in space and time. Rainfall in turn influences water availability. In South Florida, like in Ethiopia, the rainy season extends from late May or early June to late September or early October. The remainder of the year is dry. Storage can be facilitated using lakes (natural) or man-made reservoirs. Man-made reservoirs are created by building dams at appropriate locations on water ways. Excess water can be stored in lakes and reservoirs to be released when water availability is lower. An outflow control structure such as a gated culvert or spillway at the outlet of a reservoir can be operated to dictate the amount of water discharged downstream. How much water stays in the reservoir depends on the balance between inflows and outflows. Daily operations determine reservoir stages by varying relative magnitudes of inflow into and outflow from a reservoir. The process of managing stages and flows into and out of the reservoir with time constraint is reservoir operation. The temporal variation of reservoir stage is a regulation schedule. The regulation schedule is used to plan water storage and release depending on weather conditions, flood risks, and water demand following prescribed guidelines. As downstream water demand increases during dry conditions, usually in the dry season, releases are made from the reservoir making more storage available as the rainy season approaches. A typical regulation schedule shows reservoir stage rising through the wet season and falling through the dry season. A reservoir is normally operated to provide maximum available storage space at the end of the dry season and maximum stored volume at the end of the wet season available for gradual release to meet water demand during dry conditions.

Canals and Streams

Conveyance facilities include open canals, natural streams, and closed conduits. Closed conduits can provide for pressurized or free surface flow conditions. Such facilities help to move water from source to points of use.

Stage and Flow Control Means and Methods

Pumps and gravity structures control stages and discharges. Gravity structures include gated culverts, spillways, and weirs. Gate openings determine flow magnitude and stage upstream and downstream of the structure. Flow through control structures can be quantified using standardized equations. Flow through pumps can be quantified by Eq. 12.1 (Imru and Wang 2003, 2005).

$$Q = A\frac{N}{N_o} + BH^C\left(\frac{N_o}{N}\right)^{2C-1} \tag{12.1}$$

where Q is flow rate, N is actual pump speed, N_o is design pump speed, H is head across structure: A, B, C are coefficients and exponent determined through calibration.

Flow over a weir can be determined using the following equation (Imru 2001; Ci and Imru 2006).

$$Q = C_{\mathrm{w}}B_{\mathrm{e}}H^{1.5} \tag{12.2a}$$

where Q is flow rate for a free flow weir, C_{w} is weir coefficient, B_{e} is effective weir or spillway length, and H is head across structure. Head across structure is the difference between water level upstream of structure (H_{w}) and downstream of the structure (T_{w}). Flow through free flow weirs and spillways can be quantified with Eq. 12.2a and for submerged conditions with Eqs. 12.2b and 12.2c.

For submerged weir, flow can be estimated as follows, using a submergence coefficient (C_{s}) where H is head water depth above sill crest and h is tail water depth above sill crest, C_{w} is weir coefficient, and B_{e} is effective weir/spillway length.

$$Q = C_{\mathrm{s}}C_{\mathrm{w}}B_{\mathrm{e}}H^{1.5} \tag{12.2b}$$

$$C_{\mathrm{s}} = \left(1 - \left(\frac{h}{H}\right)^{1.5}\right)^{0.385} \tag{12.2c}$$

Although culverts do not lend themselves to accurate flow estimation, the following equations have been used to approximate discharge through standard configuration culverts (Eqs. 12.3a–12.3c).

$$Q = C_{\mathrm{d}}A\sqrt{\left(2gh_i - h_o - h_f\right)} \tag{12.3a}$$

In Eq. 12.3a, C_{d} is discharge coefficient, A is flow cross-sectional area in culvert, h_i is head water stage, h_o is tailwater stage, and h_f is friction loss in the culvert barrel.

Using field measurement data $\mathrm{h_f}$ can be estimated as follows.

$$h_f = Q\frac{2L}{K_i\mathrm{K}_o} \tag{12.3b}$$

where K is conveyance, i and o indicate inlet side and outlet side of barrel, respectively

$$K = \frac{1.486}{n} R^{2/3} A \tag{12.3c}$$

where A is flow cross section, R is hydraulic radius, and n is Manning's roughness coefficient.

Water Management in Ethiopia for Competing Objectives

While there are many problems in Ethiopia, the most depressing attribute which has tarnished the country's image for over four decades is hunger. Ethiopia needs to take food security as its primary objective. Most of the population is engaged in agriculture which relies primarily on rainfall. Sometimes rainfall can be unpredictable in terms of temporal and spatial distribution. That is the reason for farmers not being able to produce enough food at times and millions of people being at risk of hunger every year. There is no alternative to water for agricultural production. Since rainfall is unpredictable, irrigation is critical for sustainable food production and fighting hunger.

While conditions in the country suggest that food production should be the number one priority objective of water management in Ethiopia, attention should also be given to other important purposes including soil conservation, afforestation, sanitation and health, energy production, and related industrial development. Integrated water resources management (IWRM) is possible with food security as the central goal. If a reservoir is built for irrigation as its primary purpose, other purposes including energy production can be achieved using the same reservoir. A multipurpose reservoir in a basin is useful and effective if built as far upstream as possible to achieve the maximum irrigation benefits.

In some cases, energy production and agriculture may be in competition for the same water sources and force making choices. If there is a competition between irrigation and energy production, in Ethiopia's case irrigation should be the overriding priority. In such a situation, other energy alternatives such as wind, solar, and geothermal sources can be considered for energy production. Energy production can adversely affect water availability for irrigation if Ethiopia commits to selling electricity to foreign countries. While integrated water resources management is a widely accepted concept, if water availability dictates making difficult choices, for Ethiopia, the following can be considered a reasonable order of priorities in time.

- Food production (irrigation)
- Afforestation (ecology)
- Soil conservation (ecology)
- Domestic/industrial water supply (rural, urban)
- Hydropower

Hydropower development can be implemented in concert with the other water resources objectives listed above provided power generation facilities are located upstream of the other water consumptive endeavors. This is reasonable considering that hydropower and irrigation can benefit from the same water source if relative locations are carefully selected. An irrigation project needs to be placed downstream of a hydropower facility if in the same water course, because the water that generates energy can be used for irrigation without being reduced by the upstream power plant. Irrigation downstream of a hydropower plant can benefit from flow regulation, i.e., reduction of variation in discharge, which is characteristic of power generation. For integrated water resources management in Ethiopia, priorities can follow temporal and spatial sequencing of land and water projects for beneficial and sustainable socio-economic outcome.

IWRM priorities

Temporal Priorities → Food → Ecosystem → Energy
Spatial Priorities → Energy → Food → Ecosystem (for land with healthy vegetation upstream)
Spatial Priorities → Ecosystem → Energy → Food (for degraded land upstream)

The suggestion here is that food security (irrigation) should be the priority in time. In location (spatial priority), a hydropower generation facility needs to be placed upstream of irrigation and ecosystem projects if in the same watercourse. In some cases, it can be more beneficial or even necessary to have afforestation and erosion control projects upstream of hydropower reservoirs. Erosion control upstream of a reservoir reduces sediment transported into the reservoir improving its service life and maintaining healthy aquatic life.

It is especially important to pay attention to the quality of water flowing into a reservoir or a lake. The invasion of Lake Tana by water hyacinth is an example of severe adverse effects resulting from ignoring what the water flowing into the lake contains. It is apparent that runoff from upstream agricultural land, where a lot of fertilizer was being applied, has been flowing into the lake carrying nutrients with it. This has been going on as long as nutrient loaded water was going into the lake. The nutrients accumulating in the lake promoted the vigorous growth of water hyacinth to the detriment of fish and other native aquatic life.

Invasive plants growing in reservoirs and lakes as a result of nutrient loaded water flowing in are not unique to Lake Tana. It has happened in many parts of the world including in South Florida, USA. In South Florida, scientists have applied mechanical, chemical, and biological means and methods to mitigate the problem. There is literature on the experiences to date, successes, limitations, intended, and unintended consequences of each method employed (Abtew and Dessu 2019).

Lake Tana has another critical water management issue since the building of the Chara-Chara Dam as part of the Tana-Belles Project. The Chara-Chara Dam has severely diminished flexibility of managing Lake Tana water levels. Heavy rain in mid-September revealed the problem. At the time of design and construction in the 1980s, the inadequacy of the gates installed at Chara-Chara was suspected and recommendations were made to increase the number of gates. Initially, two outflow gates were planned. During review meetings at the time, the recommendation was to double the outflow capacity by increasing the number of gates from two to four if possible or to three at least. The turnkey contractor for the project resisted and nobody could force that company. During the mid-September 2020 flooding, the residents insisted that the solution was opening the Chara-Chara gates and were making an emotional appeal to visiting government officials at that time. Unfortunately, no one heeded the request of the area residents affected by the flood. A partial relief would have been to increase outflow from Tana via Chara-Chara as well as the hydropower route to Belles. That solution would have possibly reduced the length of time people had to suffer due to their homes and farms being flooded. The long-term solution to avoid similar incidents at the headwater of Tana is to increase the number of outflow gates at Chara-Chara Dam. This solution will also improve the situation of the Tis-Issat Falls. Tis-Issat Falls has been adversely affected by the Tana-Belles Project/Chara-Chara Dam. Its majestic beauty has been destroyed. Concerns were raised at the time of Tana-Belles Project design and construction, which were ignored by the responsible government officials at the time.

Ethiopia's Irrigation and Energy Potential

Irrigation and power potential in Ethiopia, according to a presentation by the Minister of Water, Irrigation and Energy at a workshop on "Prospective Development Plan (2013–2022)", held in the summer of 2020, is shown in Table 12.1. Annual average rainfall was indicated as 840 mm.

In Ethiopia, water plays critical roles in the production of food as well as energy. In most cases, it is possible to utilize water resources for both purposes without adverse effects to either one. However, some water utilization approaches can cause competition between the two objectives. That calls for caution in order to make sure that hydropower generation does not adversely affect irrigation or vice versa.

All medications carry warning labels to make sure users know and understand related side effects. The side effect should not be worse than the ailment the medication is supposed to treat. Similarly, it is important to understand consequences of proposed solutions. GERD is considered a major solution to Ethiopia's energy problem. Caution is warranted considering the possibility that Ethiopia can severely limit its right to use Blue Nile water for food production and ecological objectives. Ethiopia can limit its water use for irrigation if:

Table 12.1 Irrigation and energy potential in Ethiopia

Irrigation	7.5 million ha
Hydropower	45,000 MW
Solar power	5.5 kwh/m^2/day (2 GWH/ha/year)
Geothermal	10,000 MW
Wind (7 m/s, 50 m alt.)	1000 GW+

- any agreement it signs directly or indirectly stipulates that projects upstream of GERD need prior consent of riparian countries (Egypt and Sudan) or if such a precedent is created.
- Over-commits to deliver electricity, generated in the Blue Nile and other transboundary rivers, for export to foreign countries. Overuse of water for domestic power consumption can also strain the ability to develop irrigated agriculture and environmental projects, of course depending on relative locations.

To resolve competition for water between food and energy, it may be a good idea to look at alternatives such as wind, solar, geothermal, and gas for energy production and/or place hydropower facilities upstream of irrigation.

Another important consideration is that Ethiopia should first meet its domestic energy needs before venturing into exporting to foreign countries. It should generate electricity from wind and solar sources, among others, in the order of 40,000 MW or more in combination with the presently operating capacity for the current population, then, if it can produce in excess of that, think of exporting abroad. There is a lot of brainwashing narrative originating from riparian countries that misguides Ethiopia from using its water resources for increased food production to combat hunger. Ethiopia's sustainable economic growth will depend primarily on irrigated agriculture and use of wind, solar, and other renewable energy sources for power generation to support industrial growth. It is time to take the blindfold off and clearly visualize priorities to effectively use water resources for sustainable socio-economic development of the country.

Potential of Great Ethiopian Renaissance Dam (GERD)

GERD is the biggest water resources development project Ethiopia has ever undertaken. It has appealed to the collective psyche and enjoyed a broad support of Ethiopians. Some pros and cons of GERD for Ethiopia and downstream countries are listed below.

Pros for Ethiopia

- Provides a platform for Ethiopians to unite and rally around.
- It has become a symbol of national pride.
- Revealed Ethiopia's ability to use its own resources to undertake such a gigantic project despite strong opposition and lack of support from foreign powers.
- It showed that Ethiopia has no need to yield to unfair demands of foreign countries.
- Brought riparian countries to recognize and negotiate with Ethiopia.
- It created unity between the government and the people as a critical common cause.

Cons for Ethiopia

- Potential conflict between energy production on the one hand and food security and ecological objectives of consumptive use characteristics on the other. Once people in Ethiopia get used to meeting their energy needs from GERD, there is no going back. So, the entire annual flow will be dedicated to energy production leaving no opportunity to use the water source for other poverty alleviation efforts of irrigation in upstream locations.
- Uncertainty of water use agreements with riparian countries and their powerful allies who tend to force terms biased against Ethiopia's water use rights.

Pros for downstream countries

- Additional reservoir upstream at no cost to themselves.
- Regulated flow (discharge variation minimized) at Ethiopia's cost.
- Undesirable sediment load minimized.
- Flood risk reduced.
- All Blue Nile water guaranteed to flow downstream in order to meet Ethiopia's power generation needs.

Cons for downstream countries

- Flow controlled by upstream country, which will be a new uncertain experience.
- Having to recognize and negotiate with Ethiopia unlike in the past.
- Limitation on bilateral 1959 Blue Nile water sharing agreement (Degefu 2003) that had excluded Ethiopia.

A graphic representation of GERD, Fig. 12.9a, (not to scale) below shows its configuration with elevations and corresponding storage volumes. Figure 12.9b shows GERD main dam outlets and operational levels.

The hydropower potential of GERD can be estimated using discharge Q, unit weight of water γ, and static head H_p, with the equation below (12.4). Table 12.2 shows hydropower potential estimates based on Eq. 12.4. Equation for hydropower potential (Roberson et. al. 1997).

$$P = \gamma Q H_{\mathrm{p}} \tag{12.4}$$

Table 12.2 indicates estimates of power generation capacity of GERD for various combinations of water static head in meters (m) and annual volume (in bcm) of Blue Nile at the location of the project. The estimates are calculated for static head ranging from a maximum of 140 m (corresponding to maximum water surface elevation at 640 m) to a minimum static head of 40 m (corresponding to water surface elevation at 540 m). It is not likely to operate at 40 m static head. If it operates at a static head of 140 m, it will be in rare cases. The left side of the table shows installed capacities in megawatts (MW), and on the right side, corresponding annual power generation in gigawatt hours (GWH) are shown. The annual volume used for the estimates ranges

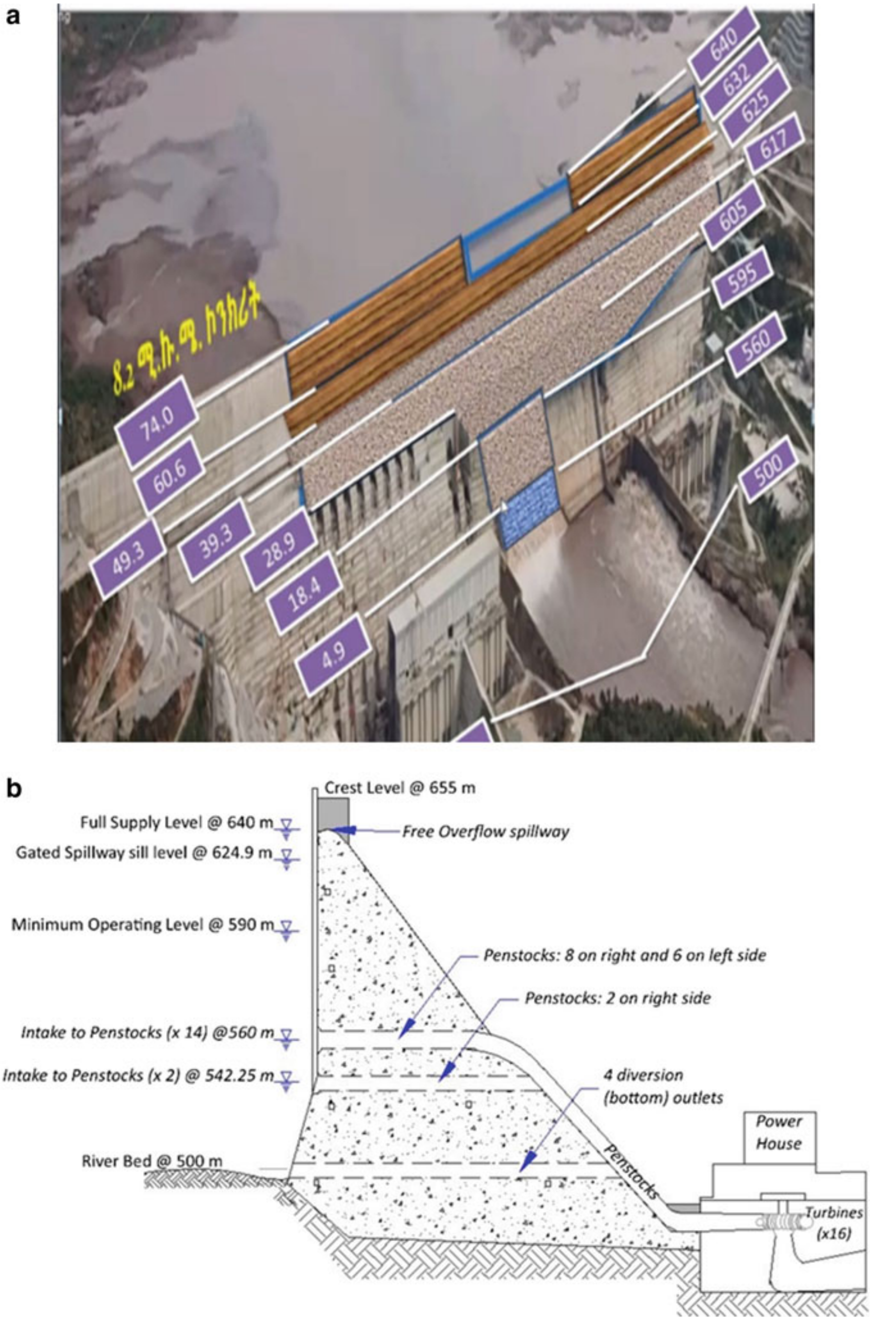


Fig. 12.9 **a** Grand Ethiopian Renaissance Dam volume (billion cubic meter (bcm), left) and corresponding water levels (m a.s.l.) (*Source* Semu Moges). **b** GERD main dam outlets and operational levels (Abtew and Dessu 2019)

Table 12.2 GERD hydropower generating capacity MW (GWH/YR) for Blue Nile annual volumes (bcm)

Static Head (meters)	Blue Nile Annual Volume through GERD (bcm)										
	70	60	50	40	30		70	60	50	40	30
	POWER CAPACITY (MW)						ANNUAL ENERGY (GWH)				
140	3108	2664	2220	1776	1332		27222	23333	19444	15556	11667
130	2886	2473	2061	1649	1237		25278	21667	18056	14444	10833
125	2775	2378	1982	1585	1189		24306	20833	17361	13889	10417
120	2664	2283	1903	1522	1142		23333	20000	16667	13333	10000
110	2442	2093	**1744**	1395	1046		21389	18333	**15278**	12222	9167
100	2220	1903	**1585**	1268	951		19444	16667	**13889**	11111	8333
95	2109	1807	**1506**	1205	904		18472	15833	**13194**	10556	7917
80	1776	1522	1268	1015	761		15556	13333	11111	8889	6667
70	1554	1332	1110	888	666		13611	11667	9722	7778	5833
60	1332	1142	951	761	571		11667	10000	8333	6667	5000
50	1110	951	793	634	476		9722	8333	6944	5556	4167
40	888	761	634	507	381		7778	6667	5556	4444	3333

from 70 bcm (extremely rare) to 30 bcm (possible during droughts). The likely capacity ranges, the annual volume of the Blue Nile at GERD can sustain, are shaded in the table. The shaded values indicate that 50 billion cubic meters of annual volume at a static head of 110 m can sustain about 1700 MW of installed capacity generating about 15,000 GWH/year. Similarly, the same annual volume at 100 m and 95 m static head can sustain 1600 MW and 1500 MW, generating 14000 and 13,000 GWH/year, respectively. The table is populated with installed capacity and annual energy estimates for various combinations of annual volume and static head. Though these are only estimates, they give a good idea of how much energy can be expected if the whole annual volume is dedicated to generating electricity only, with no allowance for water consuming endeavors such as agricultural, environmental, domestic, and industrial water supply. None of the estimates in the table shows that the annual volume of the Blue Nile at GERD can sustain an installed capacity

Table 12.3 Land use by electricity source in Acres/MW produced (*Source* https://wattsupwiththat.com/2017/08/09/the-footprint-of-energy-land-use-of-u-s-electricity-production/)

Electricity source acres per megawatt produced	
Coal	12.21
Natural gas	12.41
Nuclear	12.71
Solar	*43.5*
Wind	70.64
Hydro	315.22

anywhere close to 6000 MW. This calls for viable planning based on realistic expectations paying special attention to land and water needs of various economic development endeavors. Table 12.3 depicts land requirement to generate a megawatt of energy by different power sources.

Integrated water management can serve other goals including flood control, ecosystem enhancement, fishing, recreation, and inland navigation. It can be assumed that Ethiopia's government attempts to plan and achieve such goals. It is not clear, however, if the government is making any plans for flood control. The government's flood control effort, if any, is not visible. There has been a lot of flooding which caused damage to crop and claimed human and animal lives in the past, an example being the 2020 summer Awash River flooding.

Conclusion

Water management planning and implementation determines achievement of national goals including flood control, irrigation, environmental health, water supply, and energy generation.

Ethiopia's image of poverty and hunger needs a lot of effort for enhancement. Government should and can formulate policies that would effectively combat hunger. Policies related to water management, prioritizing irrigated agriculture for increased food production, can significantly reduce hunger and poverty in the country. Ethiopia can learn from relevant experiences of developed nations, such as the USA, to practice sustainable water management practices in its socio-economic development effort.

In cases like GERD where there will soon be competition for water between hydropower and irrigation, energy production should shift focus toward alternative renewable energy based on solar, wind, and geothermal sources. Ethiopia should meet its domestic needs before exporting energy to foreign countries. Ethiopia's desire to export energy, if based on hydropower, will severely diminish its ability to increase food production and to combat hunger.

Flood control needs to be a major goal of water management in Ethiopia. Ethiopia's water resources plan does not appear to give enough attention to flood control as a crucial goal. Ethiopia's economy can be helped to sustain water management priorities and goals by using financial savings that can result from rooting out corruption and illicit financial flows noted in Kukutschka and Martinez (2018).

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