Overview of Water Resources in Lebanon

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Where it all starts – the Hydrologic Cycle
Water Distribution

Reservoirs represented by solid boxes: 10⁹ km², fluxes represented by arrows: Sverdrups (10⁹ m³ s⁻¹)
Sources: Baumgartner & Reichel, 1972; Schmitt, 1995; Trenberth et al., 2007; Schanze et al., 2010; Steffen et al., 2010
Global Water Distribution

- Total water: 97.5% (Oceans)
- Freshwater: 2.5%
- Glaciers: 68.7%
- Groundwater: 30.1%
- Surface and atmospheric water: 6.4%

Source: WWAP 2006
Water withdrawals by sector in low-, middle-, and high-income countries.

- Domestic
- Industry
- Agriculture

Percent of withdrawals

Low, Mid Income levels, High
Water withdrawal ratios by continent

- **World**: 69% (Agriculture), 19% (Industries), 12% (Municipalities)
- **Europe**: 21% (Agriculture), 57% (Industries), 22% (Municipalities)
- **Americas**: 51% (Agriculture), 34% (Industries), 15% (Municipalities)
- **Oceania**: 60% (Agriculture), 15% (Industries), 25% (Municipalities)
- **Asia**: 81% (Agriculture), 10% (Industries), 9% (Municipalities)
- **Africa**: 82% (Agriculture), 5% (Industries), 13% (Municipalities)

Date of preparation: September 2015
How Efficient is each Sector?

The grey band represents the difference between the amount of water extracted and that actually consumed. Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is final use of water, after which it can no longer be reused. That withdrawals have increased at a much faster rate is an indication of how much more intensively we can now exploit water. Only a fraction of water extracted is lost through evaporation.

Where Does the Water Go?

Global water use:

- Rainfall:
  - Forest products
  - Grazing land biodiversity
  - Landscape 56%

- Crops livestock:
  - Rainfed agriculture 4.5%
  - Irrigated agriculture 0.6%

- Bioenergy:
  - Green water
  - Soil moisture from rain
  - Blue water
  - Rivers, Wetlands, Lakes, Groundwater

- Water storage:
  - Aquatic biodiversity fisheries
  - Open water evaporation 1.3%

- Cities and industries 0.1%

Ocean 36%

Source: Comprehensive Assessment, 2007 by Peter Rogers, Harvard University
WATER STRESS BY COUNTRY

ratio of withdrawals to supply

- Low stress (< 10%)
- Low to medium stress (10-20%)
- Medium to high stress (20-40%)
- High stress (40-80%)
- Extremely high stress (> 80%)

This map shows the average exposure of water users in each country to water stress, the ratio of total withdrawals to total renewable supply in a given area. A higher percentage means more water users are competing for limited supplies. Source: WRI Aqueduct, Gassert et al. 2013
Projected Global Water Scarcity, 2025

**Physical water scarcity:** More than 75% of river flows are allocated to agriculture, industries, or domestic purposes. This definition of scarcity — relating water availability to water demand — implies that dry areas are not necessarily water-scarce.

**Approaching physical water scarcity:** More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.

**Economic water scarcity:** Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

**Little or no water scarcity:** Abundant water resources relative to use. Less than 25% of water from rivers is withdrawn for human purposes.

**Not estimated**

*Source: International Water Management Institute.*
• Oregon State University compiled data covering every reported interaction over water going back 50 years

• Only 37 cases of reported violence between states over water (30 of them in the Middle East)

• Over the same period more than 200 water treaties were negotiated between countries.

• 1,228 cooperative events were recorded, compared with 507 conflict events, more than two-thirds of which involved only low-level verbal hostility

Hydrologic Analysis
Watershed Concept

• The basic hydrologic unit that is used in most hydrologic calculations

• A contiguous area where rainfall or runoff drain to a single outlet and is from other watersheds by a watershed divide – typically it is the topological high points around the watershed

• Are typically characterized by a single main channel and several tributaries draining into the channel

Some have many sub-watersheds
**Water Balance for a Watershed:**

Input – Output = change in storage

Input = Precipitation + Groundwater input

\[ = P + G_{in} \]

Output = Evapotranspiration + Stream Flow + Groundwater Output

\[ = ET + Q + G_{out} \]

\[ P + G_{in} - (ET + Q + G_{out}) = \Delta S \]

Note: Groundwater influence may be considered negligible.
Change in storage over a long term may also be negligible.

\[ P - (ET + Q) = 0 \]

or in case of storage facilities, \( P - Q - ET = \Delta S \)

Note, that this simplified version applies only where the assumptions are considered reasonable.
Input
Precipitation

• All forms of water that reach the earth from the atmosphere is called **Precipitation**.

• The usual forms are **rainfall**, **snowfall**, frost, hail, dew. Of all these, the first two contribute significant amounts of water.

• In nature water is present in three aggregation states:
  – **solid**: snow and ice;
  – **liquid**: pure water and solutions;
  – **gaseous**: vapors under different grades of pressure and saturation
Precipitation

- Precipitation varies spatially:
  - It tends to be heavier on or near coastlines
  - There are distortions in quantities due to orographic effects
  - It tends to be greater on the windward side of mountain barriers

- Precipitation varies temporally:
  - Variations can be seasonal, and
  - Within storms themselves
  - A variety of statistical methods are used to estimate and/or predict this variability
Representing Rainfall

- Point rainfall at a particular gage may be plotted either:
  - as accumulated total rainfall, or
  - as rainfall intensity

- A hyetograph is a plot of rainfall intensity (e.g. mm/hr) versus time (hr)

- A mass curve is a plot of cumulative rainfall (mm or in) versus time (hr)

- An intensity-duration-frequency (IDF) curve is statistical plot that relates the intensity, duration, and frequency of design storms
Graphical Representation

Accumulation from 20 to 24 hr is 5.31 in
Accumulation from 20 to 22 hr is 4.57 in
Areal Precipitation

Radars

• Radar has become an important tool for estimating spatial distribution of rainfall

• Radars estimate rainfall through a measure of the reflectivity of the radar signal by the raindrop. This relationship is called the Z-R relationship
Areal Precipitation
NEXRAD
Areal Precipitation
NEXRAD

May 9, 1993 – KTLX radar
Cumulative Rainfall
Areal Precipitation Satellites

• There are some usages of satellites for precipitation estimates.

• mostly focused on determining snow accumulation patterns - Advanced Very High Resolution Radiometer (AVHRR).

• Other satellite usage is in tracking storms especially hurricanes and typhoons
Areal Precipitation Satellites
Output – surface water
Runoff

• Quantity of water discharged in surface streams

• Includes waters that travel over the land surface and through channels to reach a stream
Hydrograph

- is a continuous plot of discharge versus time for a given location within a stream

- it represents the main hydrologic response function of a watershed

- it is the result of a combination of climate, hydrological losses, surface runoff, and base flow

- it is influenced by meteorological and physiographic factors
Components of a Hydrograph

Discharge rises quickly due to rapid surface run-off and reaches its peak just 10 hours after peak rainfall.

Precipitation causes the discharge in the river to rise.

Discharge falls at a slower rate due to base flow increasing. Base flow is the normal flow of water in the river derived from throughflow and groundwater flow.

Base flow slowly declines as throughflow declines.
A Real Hydrograph – Red River Discharge

USGS Gage 05092000: Red River of the North at Drayton, North Dakota

- 1950
- 1969
- 1979
- 1997
- 2001

Stage in Feet (Gage zero = 795.0)
Hydrograph

- Meteorological factors influencing the hydrograph are:
  - Rainfall intensity and pattern
  - Areal distribution of rainfall over the watershed
  - Size and duration of the storm event
Hydrograph

• Physiographic or watershed factors influencing the hydrograph are:
  – Size and shape of the drainage area
  – Slope of the land surface and of the main channel
  – Soil types and their distribution
  – Storage detention in the watershed
Distribution of Rainfall

Typical lag time between rainfall and runoff

Lag time between rainfall and runoff after urbanization
**Channel Evolution Model**

- **I** Stable Floodplain $Q_2$ Terrace$_1$
  - $h < h_c$

- **II** Incision $Q_{10}$ (Headcutting)
  - $h > h_c$

- **III** Widening $+Q_{10}$ (Bank Failure)
  - $h > h_c$

- **IV** Stabilizing $+Q_{10}$
  - $h = h_c$

- **V** Stable Floodplain $Q_2$ Terrace$_2$ Terrace$_1$
  - $h < h_c$

$h = \text{bank ht}$

$h_c = \text{critical bank ht.}$
Typical Stream Morphology
Output – groundwater
Groundwater:

Water occupying *all* voids within a geologic stratum
Vertical Distribution of Groundwater

Two main zones exist:

- **Zone of aeration (unsaturated)**: voids occupied by air and water

- **Zone of saturation**: voids totally occupied by water
Vertical Distribution of Groundwater

Zone of aeration or vadose zone is subdivided into:

- Soil-Water Zone
- Intermediate Vadose Zone
- Capillary Zone or Capillary Fringe

Zone of Saturation is typically not subdivided into smaller strata
Definition of an aquifer:

Formation that contains sufficiently permeable material to store, transmit, and yield water to wells and springs in sufficient quantities

– Confined aquifers
– Unconfined aquifers
Unconfined versus Confined Aquifers

UNCONFINED AQUIFER

CONFINED AQUIFER

From: Michigan State University  Cooperative Extension Service Bulletin WQ 35 What is Groundwater
(from Keller, 2000, Figure 10.9)
Aquifers and wells

- Artesian well
- Flowing artesian well
- Piezometric surface (in confined aquifer)
- Confining layer (impermeable)
- Confined aquifer
- Unconfined aquifer
- Water table well (in unconfined aquifer)
- Top of the confined aquifer
Suitable Material:

- Alluvial Deposits (mostly unconsolidated material e.g. gravel and sand) - 90% of aquifers

- Sandstone

- Limestone (cavernous limestone)

- Basalt, lava, other volcanic material, if fractured or porous or have interconnected vesicles
Aquifer Material

Sand and gravel
- Intergranular

Igneous rocks
- Crevice

Limestone
- Solution
Groundwater Flow
Groundwater Flow
Sea Springs
Groundwater Extent
Surface Water Pollution
Water Pollution

• What is water pollution:
  – Any chemical, biological, or physical change in water quality that harms living organisms or makes water unsuitable for desired uses

• Sources of pollution:
  • Point source: discharge pollutants at specific locations
    • sewage
    • industrial wastes
  – Non-point source: scattered and diffuse and cannot be traced to a specific site of discharge
    • Agricultural activity [e.g. pesticides, fertilizers, erosion].
    • urban and highway water runoff.
Pollution Sources

- Oil spills – during transportation, either accidentally or intentionally
- Dumping – sewage, chemical disposal, radioactive materials
- Land-based sources – migration of chemical substances.
- Eroded soils:
  - Organic material
  - Soil-borne pathogens
  - Chemicals and nutrients
  - Radioactive material
  - Thermal/heat
Non-accumulating pollutants

Capacity for absorption is higher than rate of injection pollutants may not accumulate.

- **Degradable Pollutants**
  - Degrade into component parts within water. Typically are organic residuals attacked and broken down by bacteria and become less harmful.

- **Nutrients**
  - stimulate growth of aquatic plant life, e.g. algae and water weeds.
  - can produce odor if in excess

- **Infectious organisms** [e.g. bacteria and viruses]
  - carried into both ground and surface water by domestic and animal wastes; industrial wastes e.g. tanning and meat packaging
  - Are live organisms that may thrive and multiply in water or decline.

- **Thermal**
  - caused by injection of heat into watercourses by an industrial plant or electric utility using surface water as a coolant, and returning the heated water to the watercourse.
Accumulating Pollutants

- Environment has little or no absorptive capacity [i.e. no natural process removes/transforms them].
  - accumulate over time.

- Examples: non-biodegradable bottles, heavy metals [e.g. lead, mercury]; persistent synthetic chemicals [e.g. dioxin, and PCBs –polychlorinated biphenyls]
  - not easily broken down; so can remain in water for long.
  - also accumulate in the food chain.
Stream Pollution

Clean Zone

Decomposition Zone

Septic Zone

Recovery Zone

Normal clean water organisms (trout, perch, bass, mayfly, stonefly)

Trash fish (carp, gar, leeches)

Fish absent, fungi, sludge worms, bacteria (anaerobic)

Trash fish (carp, gar, leeches)

Normal clean water organisms (trout, perch, bass, mayfly, stonefly)

Biological oxygen demand

Dissolved oxygen (ppm)

Types of organisms

Normal clean water organisms (trout, perch, bass, mayfly, stonefly)

Trash fish (carp, gar, leeches)

Fish absent, fungi, sludge worms, bacteria (anaerobic)

Trash fish (carp, gar, leeches)

Normal clean water organisms (trout, perch, bass, mayfly, stonefly)
Thermal Pollution

- Low dissolved oxygen
- Decreased fish population
- Altered food web
- Suffocated

Decreased fish population
Altered food web
Low dissolved oxygen
Suffocate
Groundwater Pollution
Groundwater Quality

- Dissolved minerals and chemicals
- No turbidity, few microorganisms: filtered out by soil
- Metals - Iron and manganese
- Other specific contaminants
- Some of the groundwater is contaminated with hazardous substances from landfills and septic systems, as well as illegal and uncontrolled hazardous waste dumps.
- Once contaminated, groundwater is difficult to restore.
Groundwater Pollution

- Landfills - leachates
- Septic systems, as well as
- Illegal and uncontrolled hazardous waste dumps.

Once contaminated, groundwater is difficult to restore.
Groundwater Pollution: Causes

- Coal strip mine runoff
- De-icing road salt
- Pumping well
- Waste lagoon
- Accidental spills
- Pesticides
- Buried gasoline and solvent tank
- Cesspool septic tank
- Sewer
- Landfill
- De-icing road salt
- Pesticides
- Gasoline station
- Water pumping well
- Seepage from faulty casing
- Discharge
- Confined aquifer
- Unconfined freshwater aquifer
- Groundwater flow
- Hazardous waste injection well
- Confined aquifer
Groundwater Pollution: Causes

- Solid waste tip or landfill
- Industrially polluted 'losing' river
- Industrial site drainage
- Leaking storage tanks
- In-situ sanitation
- Farmyard drainage
- Leaking sewers
- Wastewater lagoons
- Agricultural intensification
Groundwater Pollution: Causes

- Thin vadose zone & shallow water-table provides less natural attenuation,
- .: prone to pollution.
Groundwater Pollution: Causes

- Deeper and confined aquifers have much greater natural protection by the overlying ground.
Groundwater Pollution: Causes

Aquifer pollution pathways

Pathways direct from pit latrine
1. Deep penetration through strata
2. Contamination via abandoned/ unprotected dug well
3. Infiltration from a contaminated surface water body

Localised/indirect pathways
4. Direct contamination of spout (by dirty hands)
5. Surface water seepage behind tubewell casing
6. Lateral migration at water table and entry through defective casing
7. Lateral migration at water table and percolation behind the casing to the screen
Salt Water Intrusion

- Water table
- Land surface
- Sea level
- Freshwater
- Saltwater
- Interface
- Sea floor
- Density of:
  - Freshwater: 1.000 g/ml
  - Saltwater: 1.025 g/ml
- Pumping
- Well drawdown
- Groundwater withdrawal can cause saltwater intrusion and subsidence in unconsolidated sediments and unconfined aquifers.
Issues in Water Resources Management
Scales in Water Resources Management

- Real Time Control
  - Hydropower Optimization
  - Urban Drainage
  - Detention Basins
  - Flood Warning

- Management
  - Irrigation and Water Supply
  - Environmental Impact Assessment
  - Culverts
  - Minor Dams and Bridges
  - Major Dams

- Design & Long Term Planning
  - Land Use and Climate Change

- Water Use
  - Flood Protection

- Scale:
  - Weather
  - Seasonal – Annual Scale
  - Climate Scale
Dublin Principles

• International Conference on Water and the Environment held in Dublin in 1992

• *IWRM* is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
Dublin Principles

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.

2. Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.

3. Women play a central part in the provision, management and safeguarding of water.

4. Water has an economic value in all its competing uses and should be recognized as an economic good.
IWRM Criteria

1. **Equity**: The basic right for all people to have access to water of adequate quantity and quality for the sustenance of human well being;

2. **Environmental and ecological sustainability**: The present use of water resources should be managed in such a way that does not undermine the life-support system thereby compromising use by future generations of the same resource.

3. **Economic efficiency of water use**: Because of the increasing scarcity of water and financial resources, the finite and vulnerable nature of water as a resource and the demands on it, water must be used with maximum possible efficiency.
Units in BCM

- Precipitation: 8.6
- Evap./ET: 4.5
- Total Renewable Water Resources: 4.1
  - Across Boundaries: SW 0.7 – GW 0.3
  - GW to Sea: 0.4
  - Resources Remaining in Lebanon: 2.7
    - Groundwater: 0.5
    - Surface water: 2.2
Annual precipitation over Lebanon is about 8600 million m$^3$ (Mm$^3$) – mountains get most of it followed by coastal areas, the south and Bekaa’
• Lebanon has 40 streams; 17 are perennial and 23 seasonal
Metni et al. 2003
Sources

Demand – by Sector

Total: 1,473 - 1,530 Mm³/year
Major Stressors

- Growing Population
- Climate Change
• Estimated water demand 1,473 - 1,530 Mm$^3$ /year:
  – 61% going for agriculture,
  – 18% for domestic use and
  – 11% for industrial use

• Total annual renewable sources: 926m$^3$/person - lower than the benchmark of 1000m$^3$/person for water scarcity.

• By 2015, it was estimated that the individual share will drop to 839 m$^3$/person

• With the Syrian refugee influx, this has dropped to below 700 m$^3$/person

• Water infrastructure needs upgrade, almost half of the water distribution networks suffer from leakage – unaccounted for water ~ 48% nationally

• National Water Sector Strategy – plans to build dams to capture approximately 650 Mm$^3$/year
Climate Change and Water Resources: Some Current Numbers – Beirut, Lebanon

Annual Rainfall in Beirut

Max T

Min T
Water Resources and Climate Change

- Change in precipitation trends and patterns
- Rising temperature leading to decreased snow cover
- Increase in forest fires leading to decrease in ground cover
Increase in storm severity
Flood Risk and Population Distribution

Source: MoE – SNC
2010
Decrease in snow cover
Increase in the occurrence and frequency of droughts

Reference Condition 1993 - 1998

S 1 - P↓10% and ET↑10%
S 2 - P↓10% and ET↑20%
S 3 - P↓20% and ET↑10%
S 4 - P↓20% and ET↑20%
S 5 - P↓30% and ET↑10%
S 6 - P↓30% and ET↑20%
S 7 - P↓40% and ET↑10%
S 8 - P↓40% and ET↑20%
Rainfall and drought incidents

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932</td>
<td>362.2</td>
</tr>
<tr>
<td>1933</td>
<td>408.3</td>
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<tr>
<td>1956</td>
<td>500.9</td>
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<tr>
<td>1958</td>
<td>346.9</td>
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<tr>
<td>1976</td>
<td>383.4</td>
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<tr>
<td>1989</td>
<td>523.7</td>
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<td>1990</td>
<td>410.8</td>
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<tr>
<td>1999</td>
<td>496.9</td>
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In 2014, precipitation levels in Lebanon reached around 45% of the average annual precipitation nearly 370mm.
MEW considers drought conditions if rainfall is reduced by 40%
Decrease in groundcover
Current Situation

- National Water Sector Strategy – plans to build dams to capture approximately 650 Mm$^3$/year
  - Two main dams
    - The Qaraoun reservoir on the Litani River - capacity of 220 Mm$^3$
    - The Chabrouh dam in Mount Lebanon - capacity of 9 Mm$^3$

- Water infrastructure needs upgrade, almost half of the water distribution networks suffer from leakage – unaccounted for water $\sim$ 48% nationally
Current Situation

• Sewage connection is still an issue with the highest rate of connection to sewage networks being recorded in Beirut (96%) and the lowest in Batroun district (1%).

• 2 treatment plants are operational leading to the treatment of only 8% of wastewater.

• About 80% of rivers are polluted by untreated sewage water and agricultural and industrial chemical pollution.
## Institutional Structure

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<th>Ministry of Energy and Water</th>
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<td>• Regional Water Establishments</td>
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<td></td>
<td>• Litani River Authority</td>
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<tr>
<td>Councils</td>
<td>Council of the South</td>
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<td></td>
<td>• Municipalities</td>
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<td>• Local Committees</td>
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<td>Centers</td>
<td>Lebanese Center for water and wastewater management</td>
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<td></td>
<td>• Lebanese water conservation center</td>
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<tr>
<td>Indirect Ministries</td>
<td>Ministry of Finance</td>
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<td></td>
<td>• Ministry of Agriculture</td>
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<td></td>
<td>• Ministry of Environment</td>
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<td></td>
<td>• Ministry of Public Health</td>
</tr>
</tbody>
</table>
The Ministry is made up of three general directorates:

- Hydraulic and Electric Resources,
- Exploitation, and
- Oil
Institutions

Ministry of Energy and Water

- Water Policies and Strategies
- Action Plans
- Regulation
- Oversees the WEs
- Water resource management

Water Establishments

Regional WEs:
- System operation and maintenance
- Irrigation plans
- Oversees local committees

Litani River Authority:
Planning
Operating

Municipalities

- WW collection
- Operation and maintenance
- Small irrigation schemes
Sector Policies Related to Water

  - New plans to renew networks and complete distribution and transmission systems, new storage facilities, and optimization of surface water resources.
  - Artificial groundwater recharge to increase storage and to avoid or reduce salinization.
  - Wastewater plants - currently seven completed and only two operational.
  - Improve irrigation efficiency.
  - Reuse treated wastewater and sludge
  - Increased focus on demand management.

- Groundwater Assessment and Database project
- National Environmental Action Plan – Water Sector
Agriculture Sector Policies Related to Water

• Action Plans:
  – National Reforestation Plan
  – Safeguarding and restoring Lebanon’s woodland resources
  – National Land Use Master Plan
  – Strategy for Forest Fire Management
  – Green Plan
  • Water reservoirs, Land Reclamation, Reforestation.
  • Hilly Areas Sustainable Agricultural Development Project.
Climate Change Sector Policies Related to Water

- MOE; Climate Change unit

- UNFCCC Conventions, Kyoto protocol
  - National Communications
  - NEEDS
  - TNA report
  - Nationally Appropriate Mitigation Actions (NAMAs)

- Country environmental analysis

- UNCCD Convention
  - National Action Plan to Combat Desertification; subprojects dealing with land planning, water supply, demand management, promotion of sustainable agriculture, soil and natural resources conservation.
Some Successes, Gaps, and Shortcomings

• First success is in having a National Water Sector Strategy (NWSS) but it has now fallen behind the times

• Gaps:
  – Law 221 amendment which prevents proper implementation of NWSS
  – Currently operating on a project basis

• Shortcomings
  – Political bickering
  – Very limited long term funding – from national budget
  – Reactive rather proactive actions
  – Lack of awareness at all levels
  – Lack of coordination amongst ministries and between relevant agencies
  – Current staff of WEs are mostly hired as contractors for temporary periods
THANK YOU!

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