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Sustainable urban & landscape drainage selection systems & scientific identifiers in India

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ABSTRACT

Indian ancient urban drainage systems are today convertible modern sustainable drainage systems which places engineering scientific practices of surface, sub-surface drainage systems and storm water management in a Smart Capital operation of ‘Amaravati’ in State of Andhra Pradesh (AP) in India. Urban drainage systems are an essential part of water conservation and preservation. Managing and dispersing water runoff volumes and flowrates will water our vegetation without drowning it and enhance water quality. The collected water is used to replenish town’s fresh water supply. The longer the water spends on a surface the more susceptible it is to contamination. Thus selecting proper drainage systems are of vital importance in sustainable urban development. In this paper, we emphasize the significant findings of Smart & Sustainable drainage design systems for various urban applications and we also propose the scientific identifiers, “UK2AP” & “AP2UK” for AP State Capital ‘Amaravati’ development as prime course of initiative.

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1. Introduction

Sustainable or urban drainage systems are a collection of water management practices that aim to align modern drainage systems with natural water processes and are part of a larger green infrastructure strategy. Sustainable drainage systems makes urban drainage systems more compatible with the natural water cycle such as storm surge overflows, soil percolation and bio-filtration. They mitigate the human development on the natural water cycle, particularly surface runoff and water pollution trends[1] *(See Appendix-A, The Water Cycle*). In below topics we discuss the selection types and modelisation of urban and landscape drainage systems and technology transfer through developed Scientific model builders to AP State Capital Amaravati in India.

2. Types of urban drainage systems

2.1 Surface drainage system

Surface drainage systems remove excess water from the land’s surface through channels or ditches. In some cases, the ground surface is shaped or graded to create sloping toward the channels. Types of surfaces drainage systems are open drains, humps and hollows, levees, and grassed waterways. A cast-in-place trench drain is a good example of a surface drainage system [2][4].

2.2 Sub-surface drainage system

Subsurface drainage systems are implemented beneath the top layer of soil. Sometimes referred to as a French drain, they work at the root level to remove excess water. Dig ditches to install the pipes of subsurface drains [2].

2.3 Slope drainage system

Slope drainage systems are built to allow water to flow from a structure in a downward direction. It is done with the aid of pipes that move down through the slope. Since the installed pipe is anchored to an incline, it guides the water through the pipe to get it swiftly away from the structure [2].

2.4 Downspouts and gutter systems

Downspouts and gutter systems are a structure’s first defense against over-saturation from storm water. They are often drained into an aluminum extension, buried drainpipe, rain barrel, or other solution. The purpose is to move water away and route water to other drainage systems on the street or sidewalk. Sometimes they are even connected to an underground sewer line using gutter drains or “underground drains” [2].

3. Selection of landscape systems

Landscaping is an art and is important to maintain the property ensuring that the landscape gets sufficient water and that any excess is properly drained is vitally important consideration. The proper drainage system is chosen to combat standing water, runoff, and heavy rains.

3.1 Slot drain system

A slot drain is a linear drain used to evacuate water, runoff or liquids in a facility. The difference between a slot drain and the traditional trench drain is that the slot drain has no grating.

(a) Slot drain systems

The slot drain system is most similar to trench drains, but is a thinner, more modern approach to the design. Because of the slot drain's slim opening, it also eliminates the need for bulky, unsightly grates. A smaller opening doesn't mean a slot drain is any less effective, however, since the larger drain channel is actually situated underground.

Many slot drain systems can even handle the heaviest of rainfalls, transporting the water to a desired drainage point thanks to their pre-sloped design. Since the slot opening is only 0.5 to 1.25 inches wide, it helps to prevent large solid material from entering the drain, preventing clogs [5].

3.1.1 Hydroplaning

Hydroplaning also called as aquaplaning, is the partial or full separation between the wheels of a vehicle and the pavement surface caused by the excessive water pressure accumulated between the vehicle's wheels and the pavement surface. Another safety concern with wet pavement conditions is the "splash and spray" effect. When a vehicle travels on a wet pavement surface, the tyres of the vehicle accumulate the water from the pavement surface and spread clouds of small droplets into the air, resulting in poor visibility and unsafe driving conditions for road users.

Hydroplaning is directly proportional to the depth of the water film on the pavement surface and is highly influenced by fundamental factors such as the driving characteristics, vehicle dynamics, pavement conditions (geometric design, drainage design and maintenance) and several environmental factors, Chaithoo & Allopi *et al* (2012)[7]. According to Brown *et al* (2009)[6], hydroplaning can occur at travelling speeds from 89 km/hr with water depths starting at 2 mm, NAASRA (1974) states that water depths ranging between 2.5 mm and 5 mm can cause friction loss between tyres and the pavement surface without actual aquaplaning occurring. However the critical water film depth for aquaplaning to initiate may vary between 4 mm and 10 mm depending on other characteristics of the pavement surface (NAASRA 1974)[10].

3.1.2 Water film depths

A review of relevant literature has shown that the water film depth (WFD) on a pavement surface can accurately be predicated with a variety of empirical or analytical methods. These methods apply influencing variables such as drainage flow path slopes, drainage flow path lengths, rainfall intensities, Manning n-values, time of concentration and texture depths.

The RRL (Road Research Laboratory) method by Russam & Ross *et al*(1968)[12] suggested to determine the water film depth on pavements in South Africa.

This method is defined by two concepts, namely the gradient (slope) and distance (length) of the drainage flow on the pavement surface. The drainage flow path length is the minimum distance that the water must flow from the point at which it falls on the surface to the edge of the pavement and is measured along its flow path slope which depends on a combination of the pavement width, cross slope and longitudinal slope. The following equations are used and adapted from the SANRAL drainage manual, SANRAL (2013)[13] to estimate the water film depth on a pavement surface according to the RRL method:

To calculate the slope of the flow path (laminar flow conditions are assumed):

$$\boldsymbol{S_f = \sqrt{n_1^2 + n_2^2}} \tag{1}$$

Where,
S_f is the flow path slope (%)
n_1 is the pavement cross fall (%)
n_2 is the pavement gradient (%)
(The flow path slope is determined assuming a planar road surface, without super-elevation)

To calculate the length of the flow path (laminar flow conditions are assumed):

$$\boldsymbol{L_f = W * \frac{S_f}{n_1} = W * \sqrt{1 + \left(\frac{n_2}{n_1}\right)^2}} \tag{2}$$

Where,
L_f is the length of flow path (m)
W is the pavement width (m)

The water flow depth can consequently be determined as:

$$\boldsymbol{d = 4.6 * 10^{-2} * \left(L_f * I\right)^{0.5} * S_f^{-0.2}} \tag{3}$$

Where,
d is the water flow depth (mm)
I is the rainfall intensity (mm/h)

Gallaway *et al* (1979) developed a different empirical method for the United States Department of Transportation in cooperation with the Federal Highway Administration (FHWA) to accurately predict the water film depth (WFD) on a pavement surface[9]. This method is detailed in the Texas Department of Transportation's (TxDOT)[5] hydraulic design manual, Bohuslav (2004) is an empirical relationship between the drainage flow path length, the pavement slope, the rainfall intensity and the mean texture depth of the pavement surface. Gallaway *et al* (1979) and Oakden *et al* (1977) both recommended that the WFD on a pavement surface should be limited to a maximum depth of 4 mm[9][11].

$$\boldsymbol{WFD = z * \frac{TXD^{0.11} * L^{0.43} * I^{0.59}}{S^{0.42}} - TXD} \tag{4}$$

Where,
WFD is the water film depth above the top of the surface asperities (mm)
z is the constant (0.01485)
TXD is the mean pavement texture depth (mm, 0.5 mm for design)
L is the length of drainage path (m)
I is the rainfall intensity (mm/h, with a minimum of 50 mm/hr)
S is the slope of drainage path (%)
(The values for the variables provided were obtained from TxDOT's hydraulic design manual, Bohuslav (2004)).

Chaithoo and Allopi *et al* (2012) developed an independent software tool to determine flow depths on pavement surfaces by considering various hydraulic factors. The calculations confirmed that the flow depth of surface water will increase when the width of the road increases or the road gradient increases. Conversely, the flow depth will decrease if the road cross fall increases[7].

Anderson *et al* (1998)[4] have studied and identified three different techniques to control water film thickness on pavement structures:

1. Controlling the pavement geometry.
2. Implementing textured pavement surfaces (asphalt, grooved concrete, ultra-thin friction course (UTFC).
3. Installing effective drainage appurtenances.

The surface drainage systems implemented to reduce water film depths on pavements should have the capability to intercept surface water efficiently with a minimum susceptibility to clog.

3.1.3 Interception efficiency of slotted inlets

The interception efficiency (E) of an inlet is the ratio between the total amount of water flow intercepted and the total amount of flow approaching the inlet, expressed as a percentage. This is dependent on a number of influencing factors, such as the inlet characteristics (length, width, curb opening, etc), the pavement slopes (longitudinal and cross slopes), the velocity, and the flow depth of the approaching flow. The interception efficiency of an inlet decreases as the approaching flow velocity increases towards the inlet, as well as when the flow width of the approaching flow is greater than the inlet width, Brown *et al (*2009)[3].

The interception efficiency of an inlet is expressed by the following equation:

$$\boldsymbol{E} = \frac{\mathbf{Q}}{\boldsymbol{Q_i}} * \mathbf{100} \qquad (5)$$

Where,

E is the interception efficiency (%)

Q is the total flow (m^3/s)

Q_i is the intercepted flow (m^3/s)

Some slotted drain inlets are installed in the center of highways or multi-carriageway pavements to operate individually or with a type of barrier placed along the longitudinal length of the drain. This barrier can improve the road safety during wet pavement conditions, as the surface water which is not intercepted by the inlets accumulates against the barrier without flowing to the opposite side of the roadway.

Thus slot drains are incredibly durable and functional with beautiful landscaped areas. It can act as an elegant offering a stylish border to an area. They are perfect for areas with brick paving's or concrete making them an ideal option for large parks, public patio gardens, plazas, and similar areas.

3.2 French drain system

(a) French drain under construction (b) A wye-joining a perforated and solid corrugated pipe to a buried solid outlet.

A French drain, also called a weeping tile, trench drain, filter drain, blind drain, rubble drain, rock drain, drain tile, perimeter drain, land drain, French ditch, sub-surface drain, sub-soil drain, or agricultural drain, is a trench filled with gravel or rock or both with or without a perforated pipe that redirects surface water and ground water away from an area. French drains help keep water out of basements and other low areas around the property.

For French drains, HYDRUS-2D model is used for the dynamic simulation of soil water and salinity under the subsurface drainage conditions and a two-dimensional saturated-unsaturated Richards equation was adopted to describe soil water movement, Cenyao Guo *et al (2024)* [2]:

$$\frac{\partial\boldsymbol{\theta}}{\partial\mathbf{t}} - \frac{\partial}{\partial\mathbf{x}}\left[\mathbf{K}(\boldsymbol{\theta})\frac{\partial\boldsymbol{\theta}}{\partial\mathbf{x}}\right] + \frac{\partial}{\partial\mathbf{z}}\left[\mathbf{K}(\boldsymbol{\theta})\frac{\partial\boldsymbol{\theta}}{\partial\mathbf{z}}\right] + \frac{\partial\mathbf{K}(\boldsymbol{\theta})}{\partial\mathbf{z}} - \mathbf{S} \qquad (6)$$

Where,

θ is the volumetric water content

K(θ) is the unsaturated soil hydraulic conductivity

t is the time

S is a sink term which is set to 0 in this paper

x is the horizontal coordinate and

z is the vertical coordinate

French drains are primarily used to prevent ground and surface water from penetrating or damaging building foundations and as an alternative to open ditches or storm sewers for streets and highways. The variations of French drain include:

(a) Curtain drain

(b) Collector drain

(c) Fin drain

3.2.1 Curtain drain

Curtain drains are surface drains are often around foundations of homes on a sloped land. They comprise of a perforated pipe surrounded by gravel. It is similar to the traditional French drain, the gravel or aggregate material of which extends to the surface of the ground and is uncovered to permit collection of water, except that a curtain drain does not extend to the surface and instead is covered by soil in which turf grass or other vegetation may be planted so that the drain is concealed.

3.2.2 Filter drain

This form drains ground water.

3.2.3 Collector drain / Interceptor drain

Collector drains combines drainage of groundwater and interception of surface water or run off water and may connect into the underground pipes so as to rapidly divert surface water. It preferably has a cleanable filter to avoid migration of surface debris to the subterranean area that would clog the pipes.

3.2.4 Dispersal drain

This drain distributes waste water that a septic tank emits.

3.2.5 Fin drain

The fin drain comprises a subterranean perforated pipe from which extends perpendicularly upward along its length a thin vertical section, denominated the "fin" of aggregate material for drainage to the pipe length of 200 mm (7.9 in). Fin drains are used at highway edges to collect and channel seepage water at carriageway edges detailing a perforated drainage pipe wrapped in geotextile and bedded to the base of a filter stone trench.

3.3 Trench drain system

(a) Strip drain (b) Linear drain (c) Channel drain

A trench drain also called channel drain, line drain, linear drain, or strip drain; is a specific type of floor drain containing a dominant trough or channel shaped body. It is used for the rapid evacuation of surface water or for the containment of utility lines or chemical spills.

Trench drains are designed to intercept the flow of surface water runoff over vast expanses and are essentially a large drain channel with a heavy grate on top of it. This is the kind of drainage system that is found around commercial buildings such as restaurants and loading docks. They help to keep the pavement around the trench drain dry, helping to prevent slips and falls. Trench drains come in many different sizes in loading docks or city streets to pool decks. Trench drain is a classical approach as reflected to slot drains [14].

3.4 Swale drain system


(a) Runoff from the vicinity flows into an adjacent bioswale (b) Swale drain

A swale drain is essentially a ditch that gets covered or lined with either grass or another type of vegetation. The goal of a swale drain is to slow and control water runoff to prevent flooding, puddling, and soil erosion. It can also help avoid overwhelming storm drain systems with an influx of water[1].

Swale drain stand out from a regular ditch is by being shallow, it slows down the spread of water runoff allowing it to gradually filter into the soil on its own which is less harmful to the surrounding landscaping.

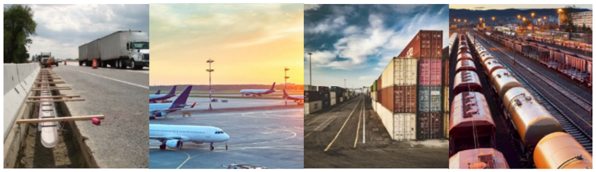
Swale drains typically have a curved profile that starts from one edge and flows gently down and then up allowing even extensive swales to look as if they are part of the sculpting of the surrounding landscape.

Swales are often used in residential and commercial areas and even in sustainable landscapes as a means of water conservation.

4. Visual applications of Smart drainage systems

The Smart drainage systems fall in variety of applications such as transportation & terminals, industrial, residential, commercial etc. depicted in Visual presentation [Image Source: www.abtdrains.com].

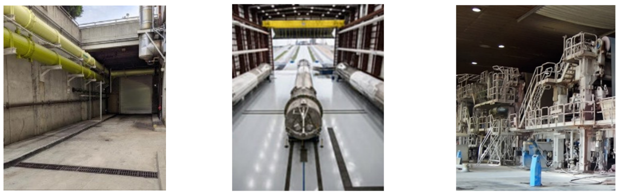
4.1 Transportation & terminal drainage solutions


(a) Roadway (b) Airport (c) Cargoport (d) Railways

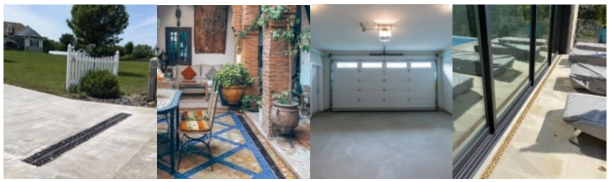

(e) Seaport (f)Tunnels & Bridges (g) Car Parking

4.2 Industrial drainage solutions


(a) Refinery (b)Manufacturing (c)Food processing (d)Pharmaceuticals


(e) Loading dock (f) Assembly plants (g) Wet processing

4.3 Residential drainage solutions


(a) Driveways (b) Patios & Sidewalks (c) Garages (d) Pool decks


(e) Downspouts (f) Yard/Lawns (g) Roof Gutter

5. Technology transfer developments of Amaravati-AP

The technology Start-up's from UK boosts the energization and investments of AP State Capital Amaravati by introducing the following models.

(A) Model-1: UK2AP

UK2AP is an advanced technology import model developed by Dan Orfester, shall act as a focal point of scientific technology transfer for all Engineering & Consultancy aspects of UK2AP for importing as built Urban & Civil infrastructure technologies from United Kingdom (UK) to Andhra Pradesh (AP).

(B) Model-2: AP2UK

While the AP2UK is a model built-in proposal that offers IT, Engineering, Multimedia professionals in exporting to United Kingdom (UK) from Andhra Pradesh (AP).

6. Results

The Smart scientific urban & landscape sustainable technologies will be adopted for Amaravati-AP Capital development. To achieve this, Dan Orfester-UK (Indian Group) have researched and innovated introducing two Model builders (1) UK2AP & (2) AP2UK for internal drawdown of exports and imports for Urban modelisation and capitalisation of Amaravati-AP. The proposed Model builder license shall be released to utilize by Andhra Pradesh State Government (www.ap.gov.in) as depicted in *Figure.1*.

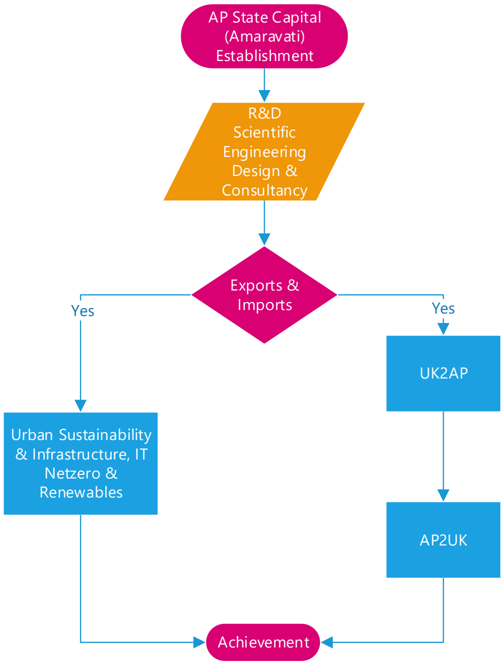


Figure.1 Model Builder of AP Capital Amaravati, India.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplement

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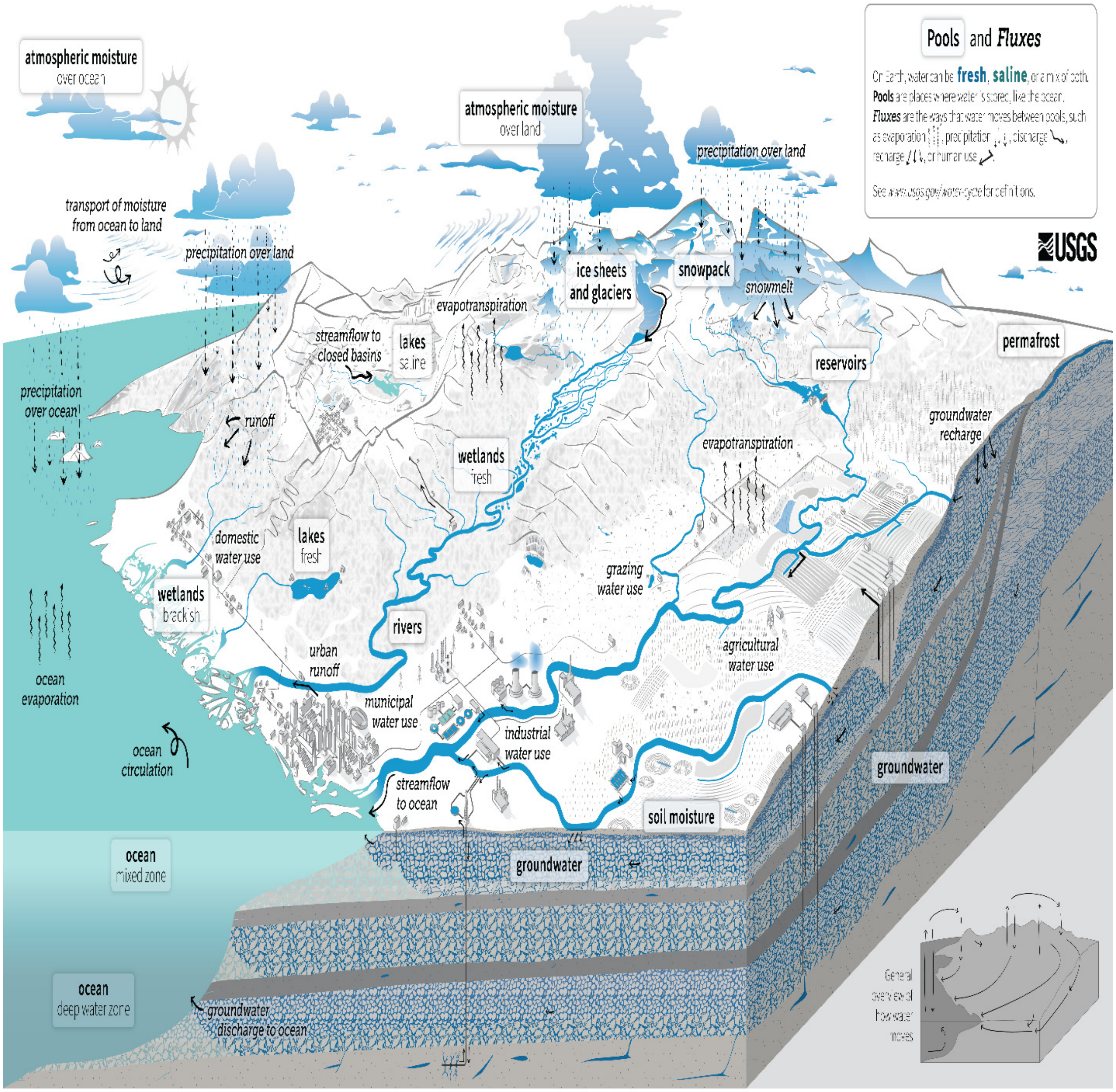
APPENDIX-A

THE WATER CYCLE

[Source: https://en.wikipedia.org/wiki/Water_cycle]



Pools and *Fluxes*

On Earth, water can be **fresh**, **saline**, or a mix of both. **Pools** are places where water is stored, like the ocean. ***Fluxes*** are the ways that water moves between pools, such as evaporation ⇡, precipitation ⇣, discharge ↘, recharge ↓, or human use ↙.

See *www.usgs.gov/water-cycle* for definitions.

The Water Cycle

The water cycle describes where water is on Earth and how it moves. Water is stored in the atmosphere, on the land surface, and below the ground. It can be a liquid, a solid, or a gas. Liquid water can be fresh, saline (salty), or a mix (brackish). Water moves between the places it is stored. Water moves at large scales and at very small scales. Water moves naturally and because of human actions. Human water use affects where water is stored, how it moves, and how clean it is.

Pools store water. 96% of all water is stored in **oceans** and is saline. On land, saline water is stored in **saline lakes.** Fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, and **wetlands**. Water is stored in solid, frozen form in **ice sheets** and **glaciers**, and in **snowpack** at high elevations or near the Earth's poles. Water vapor is a gas and is stored as **atmospheric moisture** over the ocean and land. In the soil, frozen water is stored as **permafrost** and liquid water is stored as **soil moisture.** Deeper below ground, liquid water is stored as **groundwater** in aquifers, within cracks and pores in the rock.

Fluxes move water between pools. As it moves, water can change form between liquid, solid, and gas. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the surface through **snowmelt**, **runoff**, and **streamflow**. Water moves into the ground through infiltration and **groundwater recharge**. Underground, groundwater flows within aquifers. It can return to the surface through natural **groundwater discharge** into rivers, the ocean, and from **springs**.

We alter the water cycle. We redirect rivers. We build dams to store water. We drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water to supply our **homes** and **communities.** We use it for **agricultural** irrigation and **grazing** livestock. We use it in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of water that is available depends on how much water is in each pool (water quantity). It also depends on when and how fast water moves (water timing), how much water we use (water use), and how clean the water is (water quality).

We affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is affecting the water cycle. It is affecting water quality, quantity, timing, and use. It is causing ocean acidification, sea level rise, and more extreme weather. By understanding these impacts, we can work toward using water sustainably.