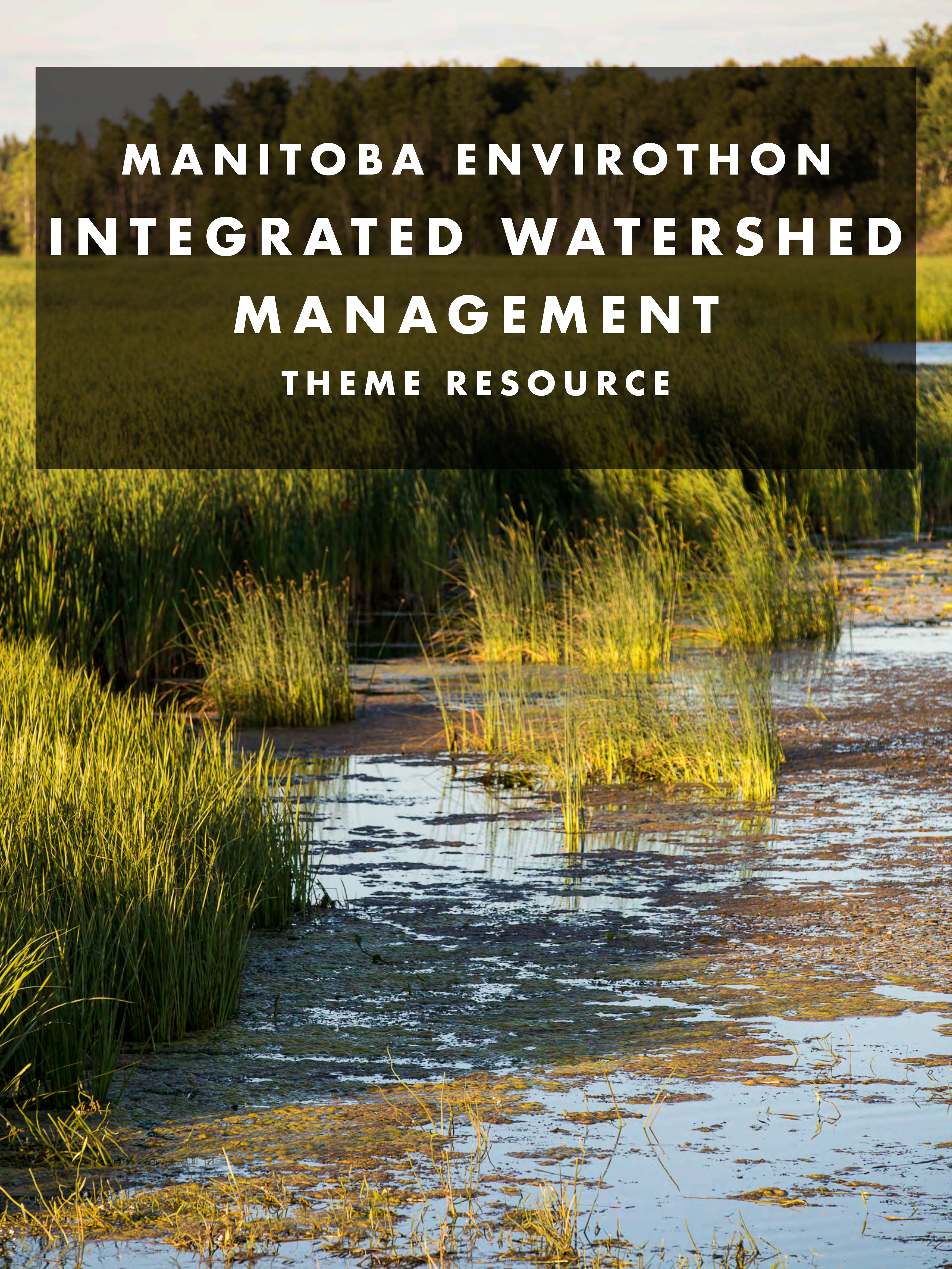

MANITOBA ENVIROTHON
INTEGRATED WATERSHED MANAGEMENT
THEME RESOURCE

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-MANITOBA ENVIROTHON-

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OVERVIEW

"Even in the vast and mysterious reaches of the sea we are brought back to the fundamental truth that nothing lives to itself."
Rachel Carson

Water is essential to human life and our economic success. Societies can extract large quantities of water from rivers, lakes, wetlands, and aquifers to fulfill the requirements of cities, agriculture, and industries. This need for freshwater has often led to us ignoring the essential benefits of water that remains in waterbodies to sustain healthy aquatic ecosystems. However, we now recognize that functionally intact and complex biological freshwater ecosystems provide important ecological services to society. Freshwater ecosystems provide flood control, transportation, cultural practices, recreation, purification of human and industrial wastes, habitat for animals and plants, as well as the production of fish and other foods and goods for market.

Aquatic ecosystems provide services that are often costly and impossible to replace when these systems become damaged. Yet, aquatic ecosystems are currently being destroyed or altered at a faster rate than previously seen, a rate that is far faster than our ability to restore these areas. Discussions about how we should be using water resources need to recognize that maintaining the integrity of these freshwater ecosystems has to be included when considering competing demands for this water. Political policies need to balance society's needs for water and the functioning of the natural ecosystems.

Historically, the requirements of intact freshwater ecosystems have been in conflict with human activity, although this conflict does not have to be sure to happen. Our challenge is to balance our needs as a society for the water resources, while protecting the complexity of our freshwater ecosystems and protect their ability to adapt. Research has allowed us to increase our understanding of adequate quantity, quality, and timing of water flow that is needed for freshwater ecosystems to function.

Long-term, ecosystems that remain the most intact are more likely to be able to withstand stressors, such as climate change and pollution. These more intact ecosystems are also more likely to retain their adaptive capacity to sustain production of a variety of goods and services through these stressors. However, these services provided by the ecosystems are costly and often impossible to replace if these systems are degraded. As such, when making decisions about the use and distribution of water resources, one needs to consider and make provisions for maintaining the integrity of freshwater ecosystems.

Freshwater ecosystems can be further restored or protected by recognizing the following:

1. Wetlands, lakes, and rivers as well as the waters that connect them underground, are ‘sinks’ in which all landscapes drain. These freshwater ecosystems are closely linked to their watersheds which they are a part of. They are strongly influenced by human modification. Small wetlands and stream networks are important to the maintenance of all water processes.
2. Dynamic variation in the patterns of flow are important. Maintaining this flow within the natural range of variation will promote the integrity and sustainability of freshwater ecosystems.
3. Additional requirements for freshwater ecosystems include sediments, and shorelines, heat (energy) and light, nutrient and chemical inputs, as well as animal and plant populations. These requirements should be within their natural ranges and not experiencing excessive amounts (e.g., high levels of nutrients leading to eutrophication).

If these natural requirements are not met, the freshwater ecosystem will experience a loss in biodiversity and ecosystem services. However, defining the requirements for restoring or protecting freshwater ecosystems through scientific studies is only the first step. Novel policy and management are also required. Historical piecemeal and consumption-oriented management approaches to water use cannot solve the current problems our freshwater ecosystems face.

In order to properly manage water resources:

1. Incorporate freshwater ecosystem needs into all local, regional, provincial, national, and global water management policies.
2. Education and communication across disciplines, including ecologists, engineers, hydrologists, economists, and local communities.
3. Include the idea of watersheds in management plans, as freshwaters should be viewed within an ecosystem context instead of political jurisdictions or geographic isolation.
4. Develop restoration plans that include ecological principles as guidelines.
5. Protect freshwater ecosystems that are currently in good conditions.
6. Recognize the importance of the cultural and social importance of water and freshwater ecosystems.

WATER

Water is present on Earth as a liquid, a solid (ice), or a gas (water vapour). Water can be frozen (liquid to solid), melted (solid to liquid), evaporated (liquid to gas), sublimated (solid to gas), and condensed (gas to liquid). Water can be mixed with other substances to create solutions, and water is a very powerful solvent that can be used to dissolve many things.

Molecules in motion

Water molecules bind to themselves through an interaction called cohesion, and to other substances through a process called adhesion. In the case of adhesion, the water molecules "stick to" the other substance, but do not change the molecular structure of the substance. For example, a droplet of water can defy gravity and stick to a vertical window without falling due to cohesion (molecules of water sticking together), surface tension (a strong film surrounding the droplet), and adhesion (the water molecules sticking to the glass). When if more water molecules are added to the droplet, it may become so large that the molecular forces can no longer overcome the downward force of gravity and the water droplet runs down the window.

Cohesion and adhesion also produce a process called capillary action, in which molecules of water move upwards through very small tubes against gravity. In this case, the water molecules want to stick to the tube (adhesion), and also want to stick together (cohesion), which forces water up through the tube continuously. Without this property, the nutrients needed by plants and trees would remain in the soil.

SNOW, ICE, AND GLACIERS

Snow

Snow only occurs in parts of the world but has extensive effects on regional weather patterns. The study of snow, its formation, its locations, and how a snowpack changes over time, improves our ability to predict storms and learn about the relationships between snow and weather.

In Canada, an average of 36% of the total annual precipitation is in the form of snow, with wide variability across the country. In the North, 50% of precipitation is snow, in the Prairies it's 25%, and in southern Ontario it's as little as 5%.

Snow impacts the distribution of streamflow year-round. Water is stored on the landscape as snow during winter months instead of immediately infiltrating the soil or running off into stream channels like rainfall. Snow melt in the spring introduces a large amount of water to local streams. If lots of snow falls in the winter, there may be large floods in the spring, but if a winter is relatively dry there will not be as much potential for flooding.

Physical properties of snow

Snow is precipitation in the form of ice crystals. When it falls to the ground and accumulates, it may be considered water in storage and is part of the cryosphere (the portion of the earth's surface where water is in solid form). On the ground, it is an accumulation of packed ice crystals, and the conditions of this "snowpack" are determined by several qualities, including colour, temperature, and water equivalent. With the fluctuation of weather, the snowpack may vary as well.

Snow falls in several forms:

- Snow flakes are 6-sided clusters of ice crystals that form in a cloud and fall to earth directly.

- Snow pellets, or graupel, form when supercooled water droplets are collected and freeze on falling snowflakes.
- Sleet is drops of rain or drizzle that freeze into ice.

Most snow and ice appears white because visible light is white, and most visible light is reflected back by the snow or ice surface. Snow may also appear blue if light is scattered multiple times through the ice crystals. Particles or organisms present in the snow may also affect the colour of the snow. Watermelon snow, which appears red or pink in colour, occurs because of a freshwater algae that contains a bright red pigment. Watermelon snow is commonly seen in high alpine areas and coastal polar regions during the summertime. Iron rich water, as seen in some glaciers, can cause the ice to have a deep red colour.

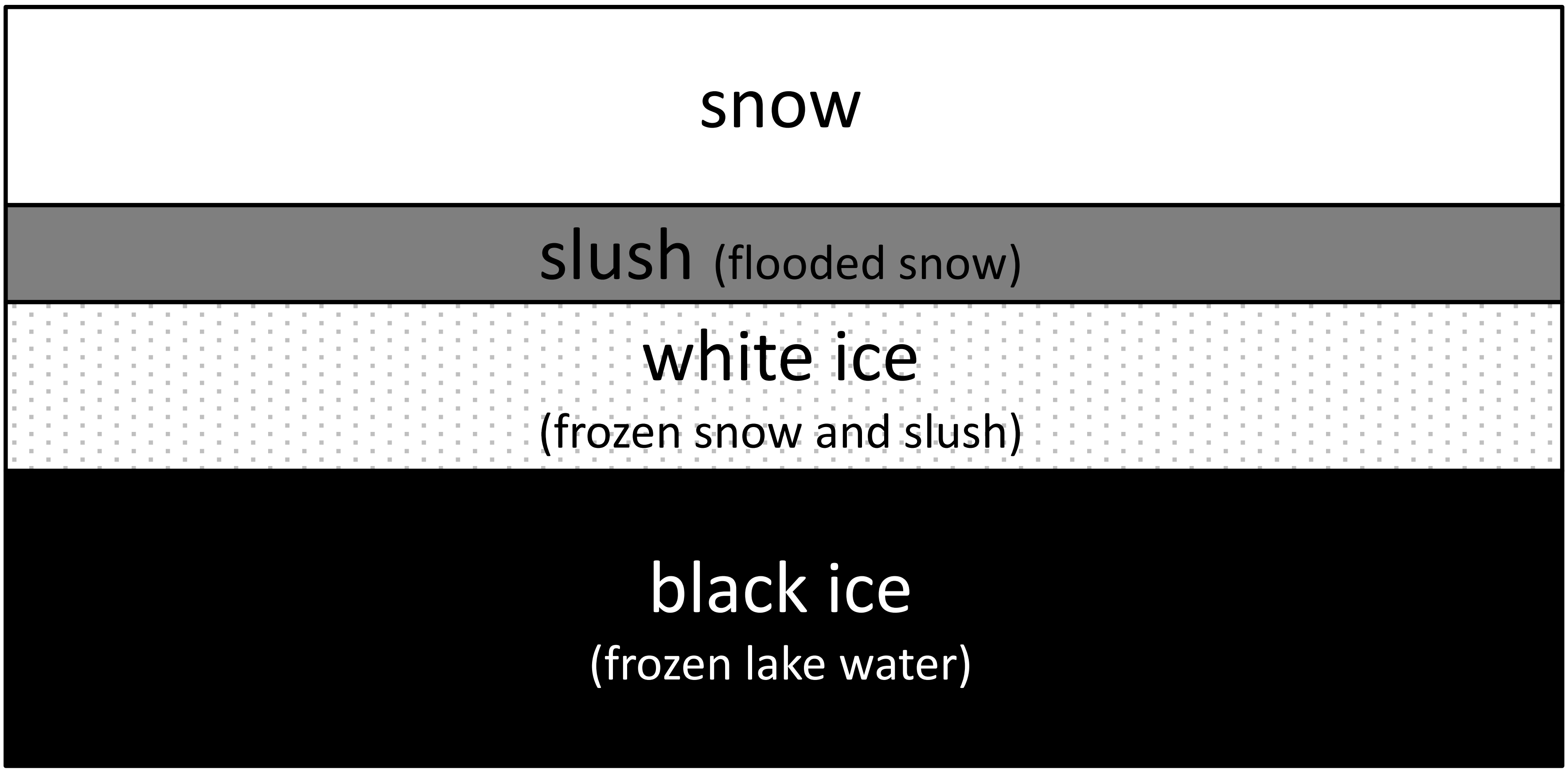
Snow is an excellent insulator. New snow contains a high percentage of air trapped within its crystals. Uncompacted, fresh snow is up to 90-95% trapped air. Since the air is trapped, the transfer of heat is reduced.

Ice

Ice forms on the surface of water bodies when the temperature drops below freezing. The nature of these ice formations may be simple as a floating layer that thickens gradually, or it may be very complex, especially when water if fast flowing.

Still water bodies, such as lakes and ponds, may freeze over completely in a short period of time (hours to days). Once the first layer of ice forms on the surface of a water body, further growth proceeds both downwards (as water freezes to the underside of the ice layer), and upwards (as snow and slush accumulate on the frozen surface). The presence of snow on top of the ice offers insulation and slows the process of ice formation.

When ice forms across the surface of a still water body it seals off the water from the atmosphere, preventing exchange of gases such as oxygen and carbon dioxide. It also blocks out much of the light, making it difficult for aquatic plants and algae to produce oxygen. During the winter oxygen levels in the lake slowly decline, with a large anoxic zone (no oxygen) building up at the bottom of the lake. This can present a serious challenge to organisms that require oxygen, because if the lake stays frozen for too long, oxygen levels can become low enough to kill them.



Lake ice diagram. Ice grows downward as lake water freezes to the underside of the ice, creating black ice. Ice grows upward when snow and slush accumulate and freeze on the surface, creating white ice. Slush is flooded snow, and the snow cover is dry (non-flooded) snow. Additional layers may be present between or within black and white layers.

Flowing water bodies such as rivers take longer to freeze than still ones because the motion of the water prevents ice from forming. However, once temperatures are cold enough even the motion of the water is not enough to keep the surface from freezing. Ice formed on flowing water may be flat and smooth or may be uneven and broken, depending on conditions during freeze-up. During spring melt, broken ice can accumulate on rivers at obstructed sections (such as a dam). These deposits may block large portions of the river's flow and cause local flooding. Additionally, the chunks of ice may collide with structures (e.g., bridges) and cause major damage.

Glaciers

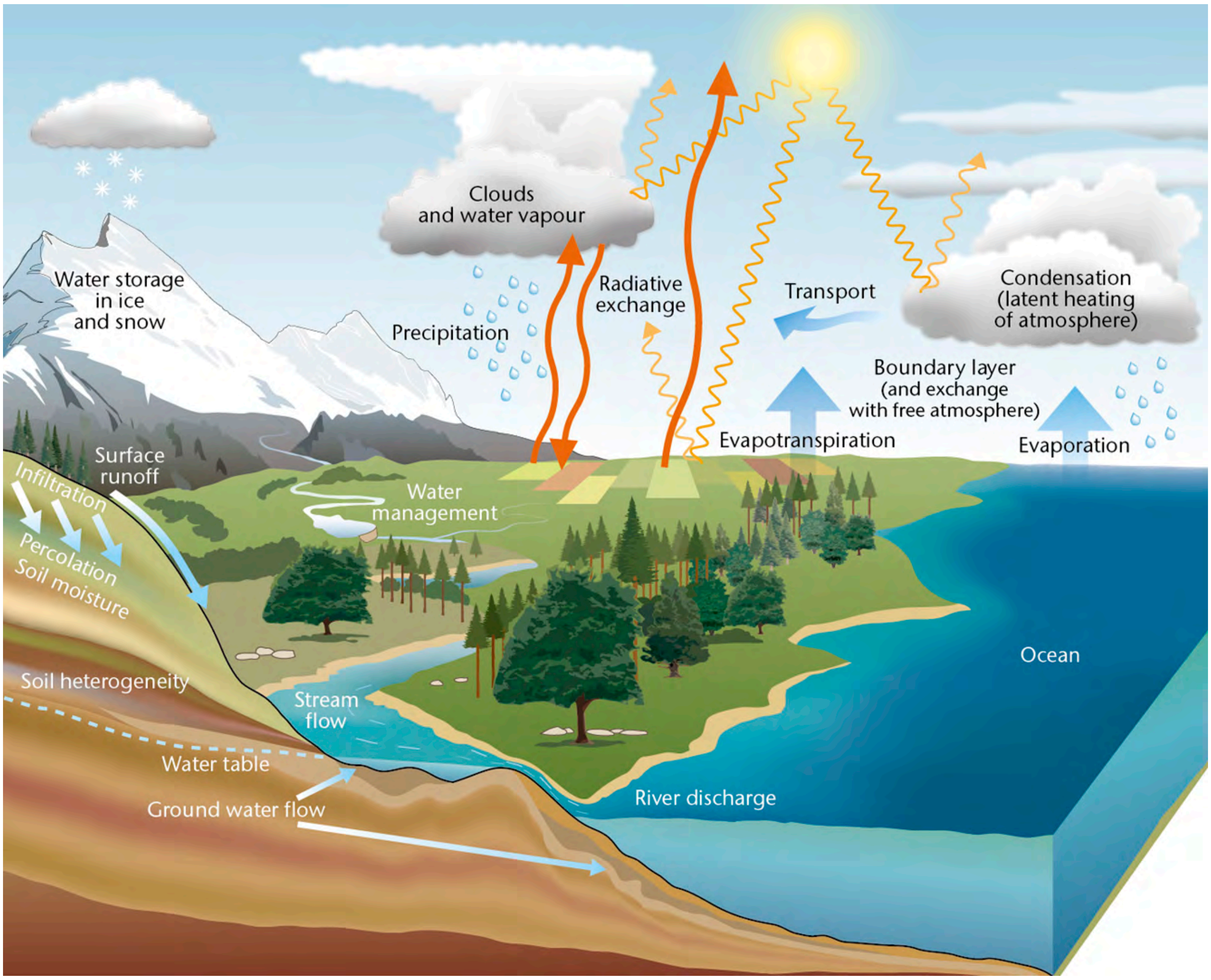
A large quantity of the fresh water on earth is frozen in high mountain glaciers. Snow deposited at high altitudes over many years settles and compacts so much over time (millennia) that it turns into glacial ice. This ice slowly proceeds downslope under the pull of gravity like a frozen river and eventually melts to become part of streamflow at lower (warmer) elevations. If the rate of melting is greater than the rate of accumulation, the glacier recedes (appears to retreat uphill). If the rate of melting is less, the glacier advances (appears to move downhill). Unlike rivers fed by snowmelt that experience peak flow in spring, glacier-fed rivers reach their peak during hot summer weather.

Glaciers slow the movement of water through they hydrologic cycle by "trapping" water for thousands of years. In this way, glaciers are excellent freshwater storehouses, releasing water slowly over time. Glaciers, however, can also release water suddenly with great force. Glacier-outburst floods, called jökulhlaups (Icelandic, "glacial run"), can be devastating to flooded areas.

Polar hydrologic cycle

The cold polar climate slows many processes in the hydrologic cycle. For example, in arctic regions where water bodies remain ice-covered for six to ten months of the year, there is little evaporation or precipitation occurring in winter. Runoff from winter snowfall is concentrated for the brief spring snowmelt, breakup, and flooding. Melting snow can also contribute to runoff for substantial parts of the summer. For example, it takes about two months for snowmelt to make its way through the Mackenzie River system to the Beaufort Sea.

HYDROLOGIC CYCLE



The total amount of water on earth has been constant in quantity – little water has been added or lost over time. The same molecules of water have been transferred over and over again from water bodies to atmosphere to land and back to the water bodies for millennia. This continuous cycle is known as the '*hydrologic cycle*'. The sun acts as the "engine" for the hydrologic cycle, causing evaporation.

Evaporation (liquid to gas)

When heated, molecules on the surface of liquid water become sufficiently energized to break their bonds with the other water molecules and rise as an invisible vapour in the atmosphere.

Transpiration (liquid to gas from plants)

Plant leaves emit water vapour formed during respiration from their pores (stomata). An actively growing plant will transpire 5-10 times as much water as it can hold every day. Transpiration is sort of the equivalent of sweating in animals.

Condensation (vapour to liquid)

Condensation occurs when air saturated with water vapour cools so much that The cooling and condensation of water vapour on dust particles occurs as it rises. The condensed water vapour can become a liquid again or become solid (ice, hair, or snow). These particles then come together and form clouds.

Precipitation (liquid or solid)

Precipitation occurs when small droplets (liquid) or crystals (solid) water fall from the atmosphere to the land. Tiny ice pellets form in the clouds when water condenses and freezes around dust particles (water adsorbs to the dust particle). If the air is above freezing at ground level, the precipitation will fall as rain (or, occasionally, hail), and if it's below freezing, the precipitation will fall as snow or another type of icy precipitation.

Precipitation may also occur when a warm air mass is forced to a higher elevation due to landscape features. When it cools it is not able to hold as much water vapour and the excess moisture "falls out" of the air mass as precipitation. For example, when air masses rise over mountains they cool, which results in condensation and precipitation at the base and slopes of the mountains.

Runoff

Snowmelt or excessive rain can travel across the surface of the land in the form of overland flow until the water reaches a water body. This "runoff" water travels from the place it was deposited on the landscape into larger and larger streams. As the water in an area drains, runoff is the visible flow of water in rivers, creeks, and lakes.

Percolation

Percolation occurs when water moves from the surface of the land into deeper layers, infiltrating the ground through cracks, joints, and pores in the soil and rocks. When the water reaches the water table, it becomes groundwater.

Groundwater

Water held underground in soil or in pores and crevices in rock is called groundwater. In some areas, if the geology is correct, the groundwater can flow to support streams (under- and above-ground) and can be tapped by wells. Groundwater can last for long periods of time underground without evaporating (> 1000 years).

Water table

The upper level of an underground surface in which the soil or rocks are permanently saturated with water.

WATER-CLIMATE RELATIONSHIP

Water is intimately related to climate through the hydrologic cycle. The climate of a region will strongly impact the water supply within that region through precipitation and evaporative loss. Large water bodies (e.g., ocean, Lake Winnipeg, Great Lakes, Lake Baikal, etc.), have a moderating effect on local climatic conditions as they can serve as large sources and sinks for heat. Regions close to large water bodies will often have milder winters and cooler summers.

An enormous amount of solar energy is required to evaporate water into the atmosphere due to the high heat capacity of water. Heat from the sun becomes trapped in the atmosphere by greenhouse gases, with water vapor being the most plentiful. Energy (heat) is released into the atmosphere as water vapour condenses to precipitation. As such, water acts as an energy transfer and storage medium for the climate system.

TYPES OF WATER BODIES

Lake – a lake is a sizeable water body formed when water fills a depression in the landscape. Lakes are surrounded by land and fed by rivers, streams, and local precipitation. Lakes may freeze over partially or fully in winter, but liquid water will always remain present below the ice. Lakes are often classified based on a variety of conditions, such as their chemical or biological condition.

Lake Mapourika
© Richard Palmer

Pond – a pond is similar to a lake, but tends to be smaller and shallower. Ponds are typically formed in natural hollows such as limestone sinks, holes created by beaver work, or even human led digging. Ponds may exist seasonally or from year to year, and may freeze solid in winter.

Waikato River

River/Stream – rivers and streams are bodies of fresh, flowing water. The water will either run permanently or seasonally into another body of water such as a pond, lake, or ocean. The difference between rivers, streams, and creeks is based on size of the water body.

Ocean - a very large expanse of salt water surrounding the continents and covering a large proportion of the surface of the globe. The ocean is divided up into several "oceans" geographically, but in fact all oceans on earth are connected.

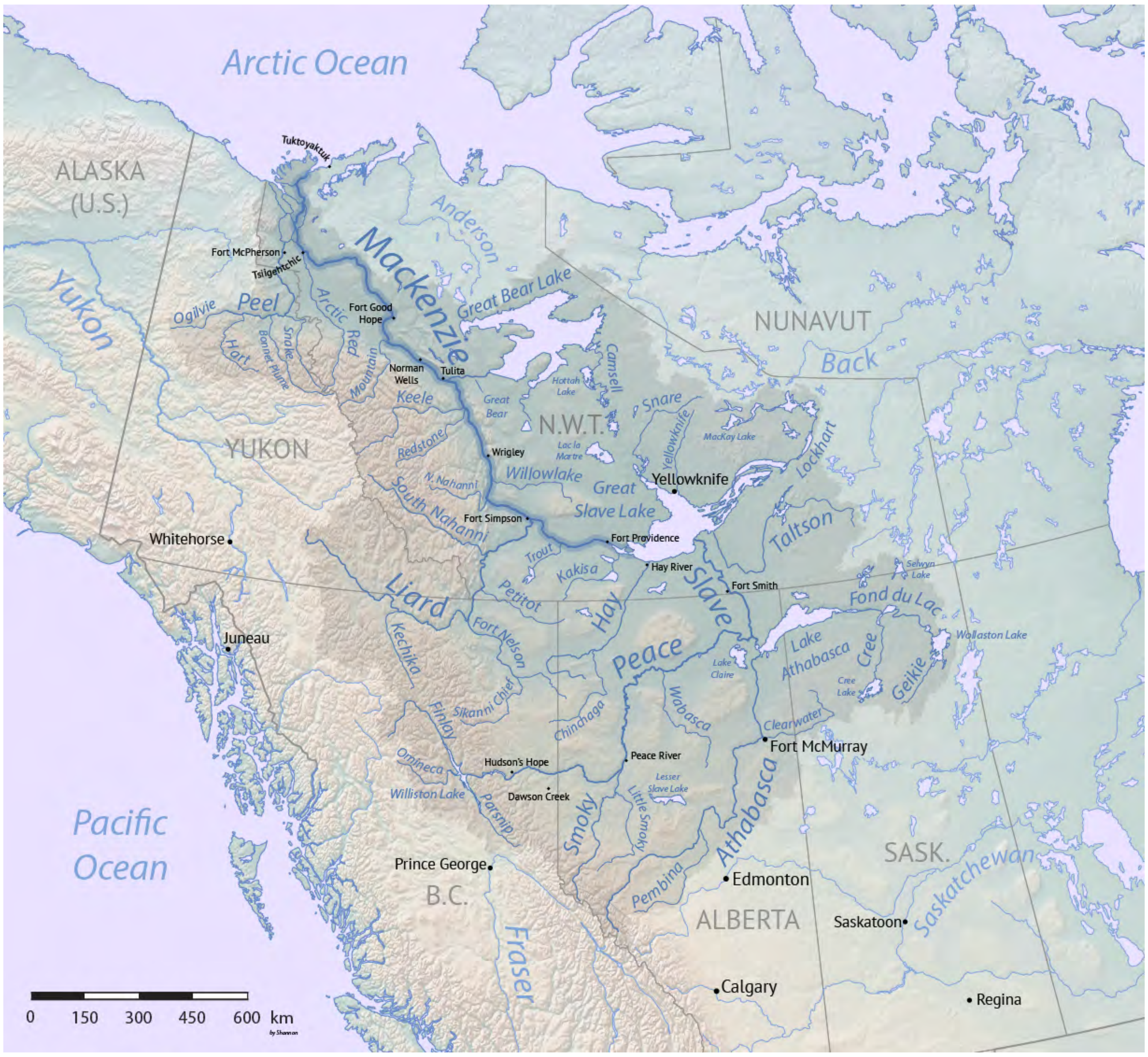
Estuary
© Nathan Anderson

Estuary – an estuary is a partially enclosed coastal body of brackish water (mix of salt and freshwater), with one or more rivers or streams flowing into it and a free connection to the open sea.

Wetland – a wetland is a nutrient-rich ecosystem formed when water is trapped on the landscape due to poor drainage, occasional flooding, or coastal barriers. Wetlands are lands that are permanently or temporarily submerged or permeated by water and characterized by plants adapted to saturated soil-conditions.

Wetland
© U.S. Fish and Wildlife Service

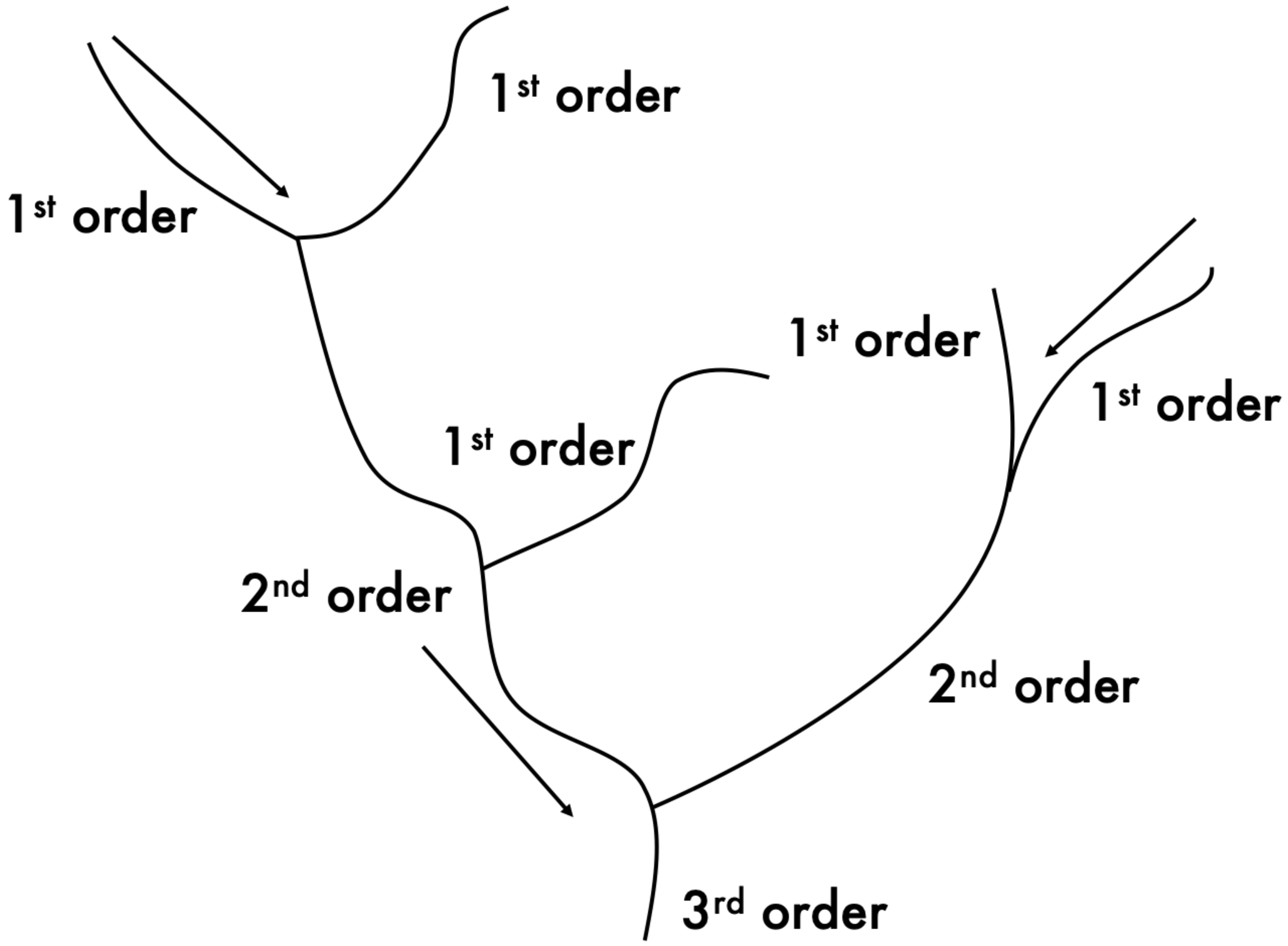
WATERSHED BASICS



WATERSHED AREAS

The area of land drained by a stream/river is called the stream/river's watershed or drainage basin. All precipitation and groundwater in this area will eventually flow into the stream and be carried elsewhere. Since water will always flow downhill, a stream's watershed is separated from the watersheds of neighbouring streams by higher lands called drainage divides. All water that falls on one side of a drainage divide will end up in one watershed, while water that falls on the other side will end up in another one. If you were to stand by a stream at the bottom of a valley, you might look up and see hills all around you. All the land that slopes down toward your stream is part of the stream's watershed.

Hydrologic Unit Codes (HUC) can be used to describe the size of a watershed, based on the geography that is most relevant to the watersheds area. The ***Strahler stream order system*** treats streams in a hierarchy system. A stream or river segment within a river network is treated as a node in a tree. The next segment downstream is treated as its parent. When two first-order streams come together, they form a second-order stream; when two second-order streams come together, they form a third-order stream, etc.



The ***Pfafstetter Coding System*** will also separate drainage areas in a hierarchical fashion, with "level 1" watersheds at continental scales, subdivided into smaller level 2 watersheds, which are divided into level 3 watersheds, etc. In this system, each watershed is assigned a unique number, called a **Pfafsetter Code**, based on its location within the overall drainage system.

You can look at the watersheds on a landscape at many scales, from locally to continentally. The watershed of a tiny stream will be much smaller than that of a river; the river's watershed is made up of all the watersheds of its tributaries (streams that feed the river) combined. Canada has five continental watersheds. Water in each of these watersheds will end up in: Pacific Ocean, Arctic Ocean, Atlantic Ocean, Hudson Bay, and Gulf of Mexico. The largest watershed in North America is the Mississippi River Watershed, which drains 3 million square kilometres from all or parts of 31 U.S. states and two Canadian provinces stretching from the Rockies to the Appalachians!

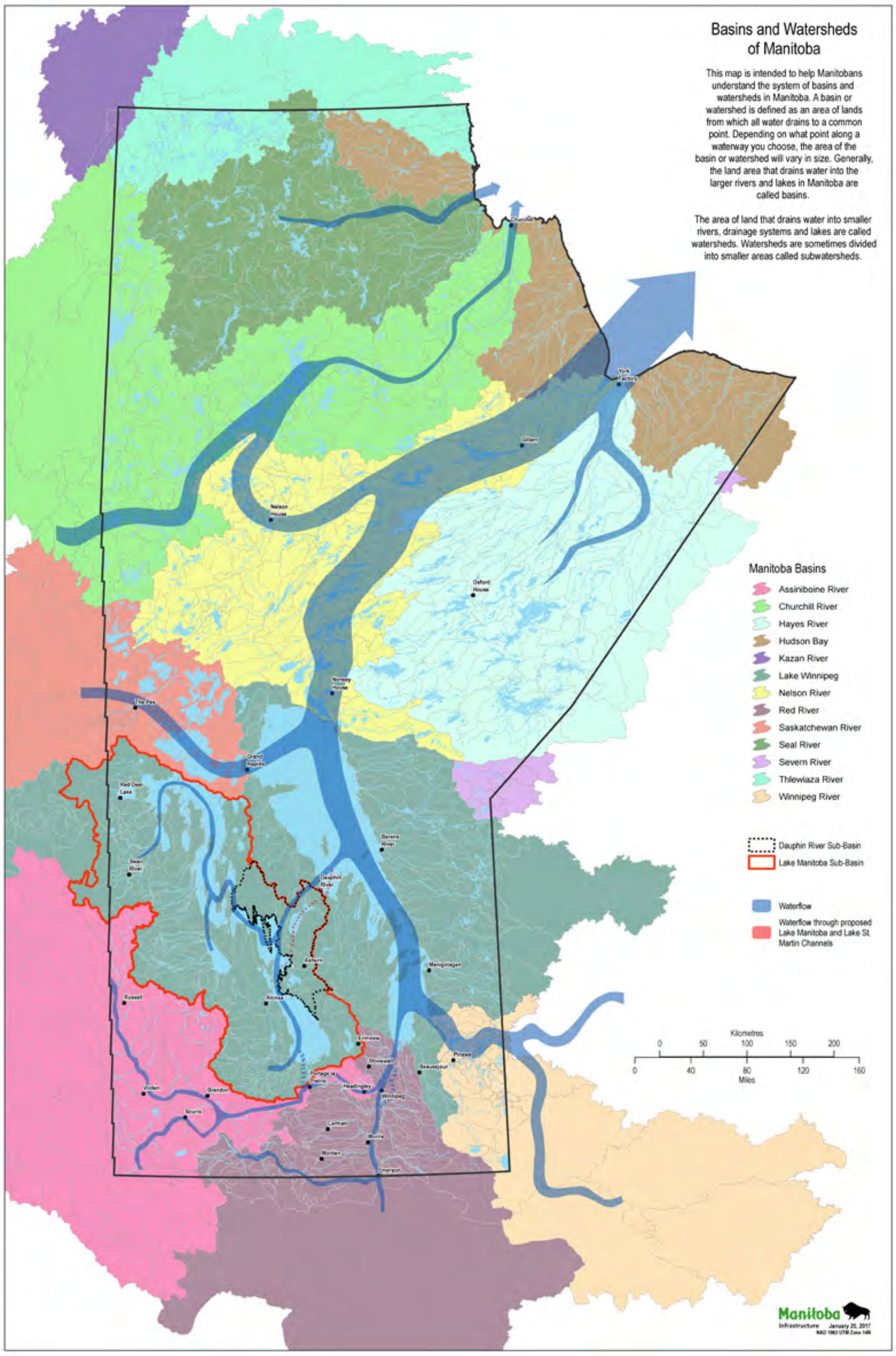
Water will flow from thousands of creeks and streams on higher ground to rivers and eventually move to a large waterbody. As this water moves, it will often pick up pollutants, sediments, and nutrients, which will impact watershed ecology, and eventually the reservoir, bay, or ocean where it ends up. However, not all water will flow directly into the sea. If rain falls on dry ground it often can soak into the ground. The groundwater will then remain in the soil, and eventually it will move into the nearest stream. Some of this groundwater may end up moving even deeper into aquifers. Alternatively, if the soil contains large amounts of hard clay, much of the waster will not infiltrate the soil, and the water will run to lower ground. During periods of heavy rain and snow, this water may run off impervious surfaces (e.g., parking lots, roads, buildings, and other structures) because it cannot infiltrate these surfaces. This water will often move into storm drains in urban areas. If there is a lot of precipitation at the same time, it can often overwhelm streams and rivers, which can result in flooding.

Canada continental watersheds. The water that falls in each area will eventually end up in the water bodies noted. All water in Manitoba will eventually end up in Hudson Bay.

Modified from © 2018 Canadian Geographic

Watersheds in Manitoba

The figure below illustrates the major watersheds of Manitoba, which can be further subdivided into many smaller and smaller watersheds, or sub-basins, depending on the spatial scale in which one is interested. Note that most of these watersheds extend beyond provincial borders, including reaching all the way to the continental divide in the Rocky Mountains. Most of Manitoba lies at a lower average elevation than its neighbouring provinces and states, meaning that much of the runoff from these neighbouring regions flows into, and through, Manitoba. All water in Manitoba eventually makes its way north to Hudson Bay.



Basins and Watersheds of Manitoba

This map is intended to help Manitobans understand the system of basins and watersheds in Manitoba. A basin or watershed is defined as an area of lands from which all water drains to a common point. Depending on what point along a waterway you choose, the area of the basin or watershed will vary in size. Generally, the land area that drains water into the larger rivers and lakes in Manitoba are called basins.

The area of land that drains water into smaller rivers, drainage systems and lakes are called watersheds. Watersheds are sometimes divided into smaller areas called subwatersheds.

Manitoba Watersheds

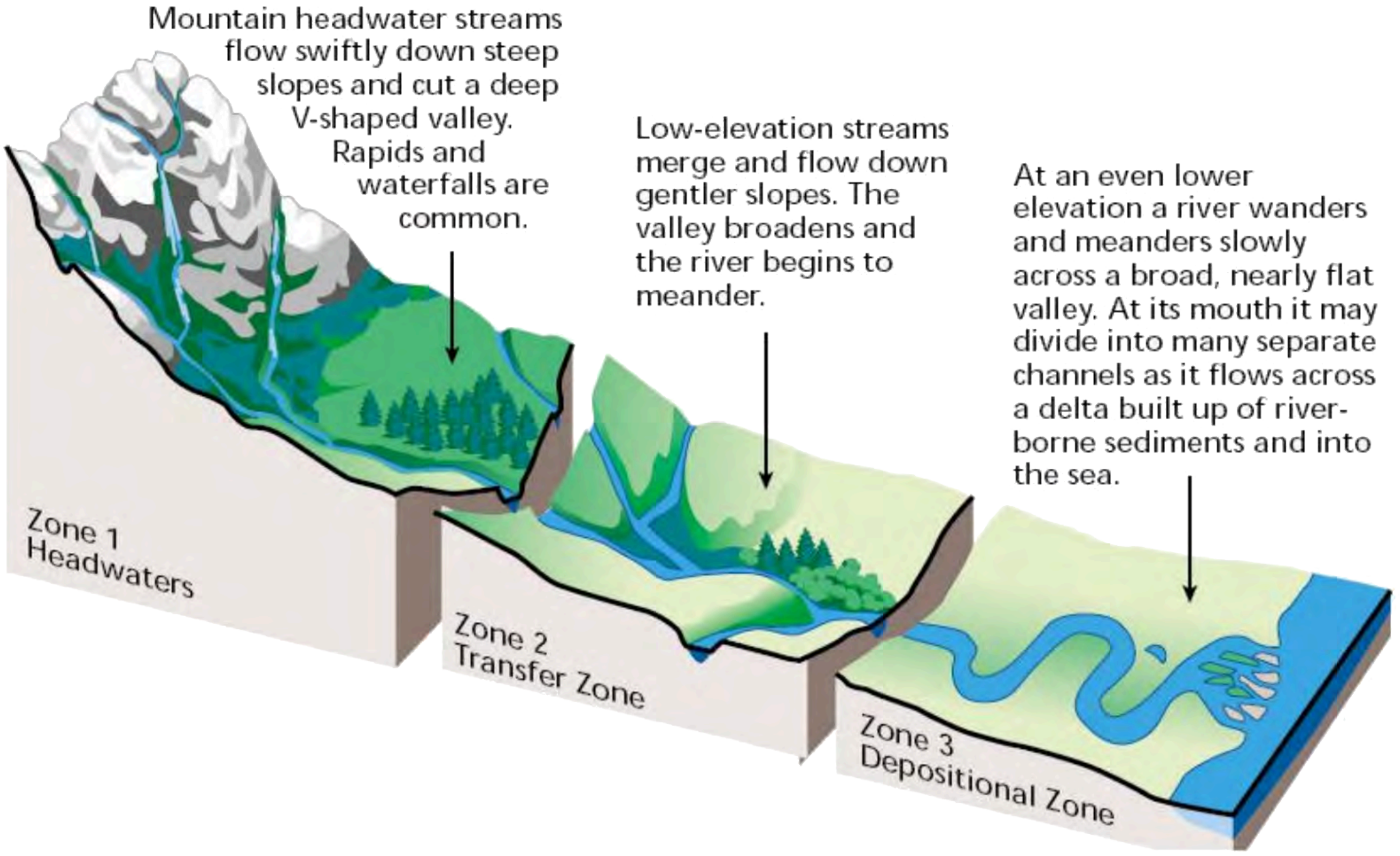
© Government of Manitoba

SHAPING THE LANDSCAPE

Flowing water changes the landscape it travels through. Given enough time, a stream can carve deep canyons through solid rock. For example, the Grand Canyon was initially formed by erosion from the river.

The volume of water and the speed and timing of the flows governs how a river shapes the surrounding landscape and the species found within it. Rainfall, snowmelt, and groundwater all contribute to the volume of flow, varying by season and year. Most high flows are caused by spring snowmelt in Canada. Rainstorms can also cause high flows and floods, especially on small streams. In Canada, the lowest flows for streams generally occur in late summer, when precipitation is low and evaporation and consumption by plants is high, and in late winter, when rivers are ice-covered, and the precipitation is stored until spring in the form of ice and snow.

In steep, narrow areas such as at the "top" (highest points) of the watershed, water flows quickly and may cut down deeply into the substrate (soil and rock of the stream bed). In gently-sloping, wide areas such as those found "lower down" in the watershed, water flows slowly and may deposit some of the materials it carries in the flow (e.g., sand particles). Over time, slow-flowing rivers will meander back and forth across the landscape instead of cutting a straight line. The Red and Assiniboine Rivers are good examples of relatively slow-flowing, gently-sloped rivers, and as a result they both have many bends and sand deposits in them.



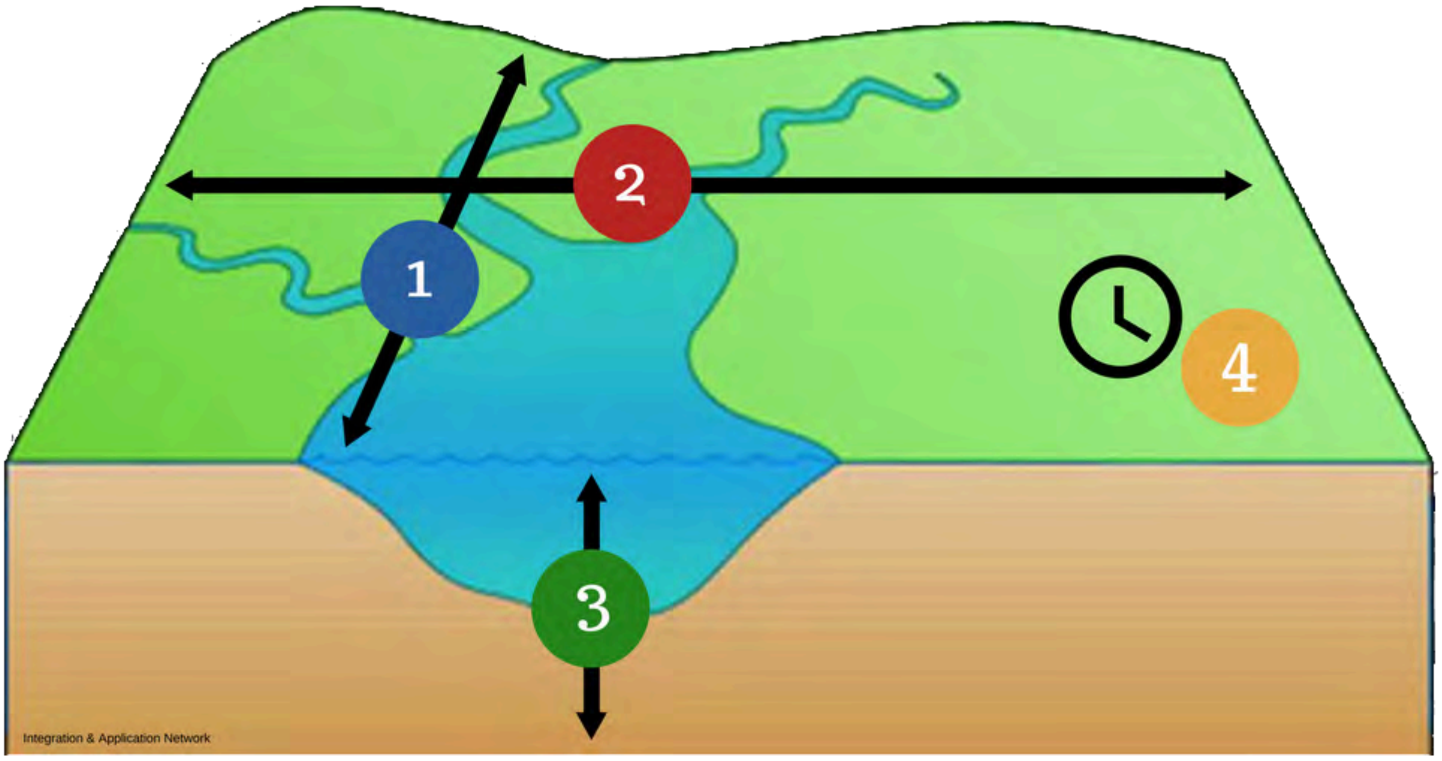
WATERSHED STRUCTURE

Watersheds are composed of flowing waters (mainly rivers and streams, with associated wetlands and riparian areas), still waters (lakes and ponds with associated wetlands and shorelands), and upland areas. Almost 9% (891 163 km^2) of Canada's total area is covered by freshwater, with 60% of all of Canada's freshwater draining north.

Lotic (Flowing) Systems

Canadian rivers release close to 9% of the worlds renewable water supply. These systems include which include springs and seeps, rivers, streams, creeks, brooks and side channels.

The four-dimensional concept (by Ward 1989) suggests that flowing systems exists in four-dimensions (see below):



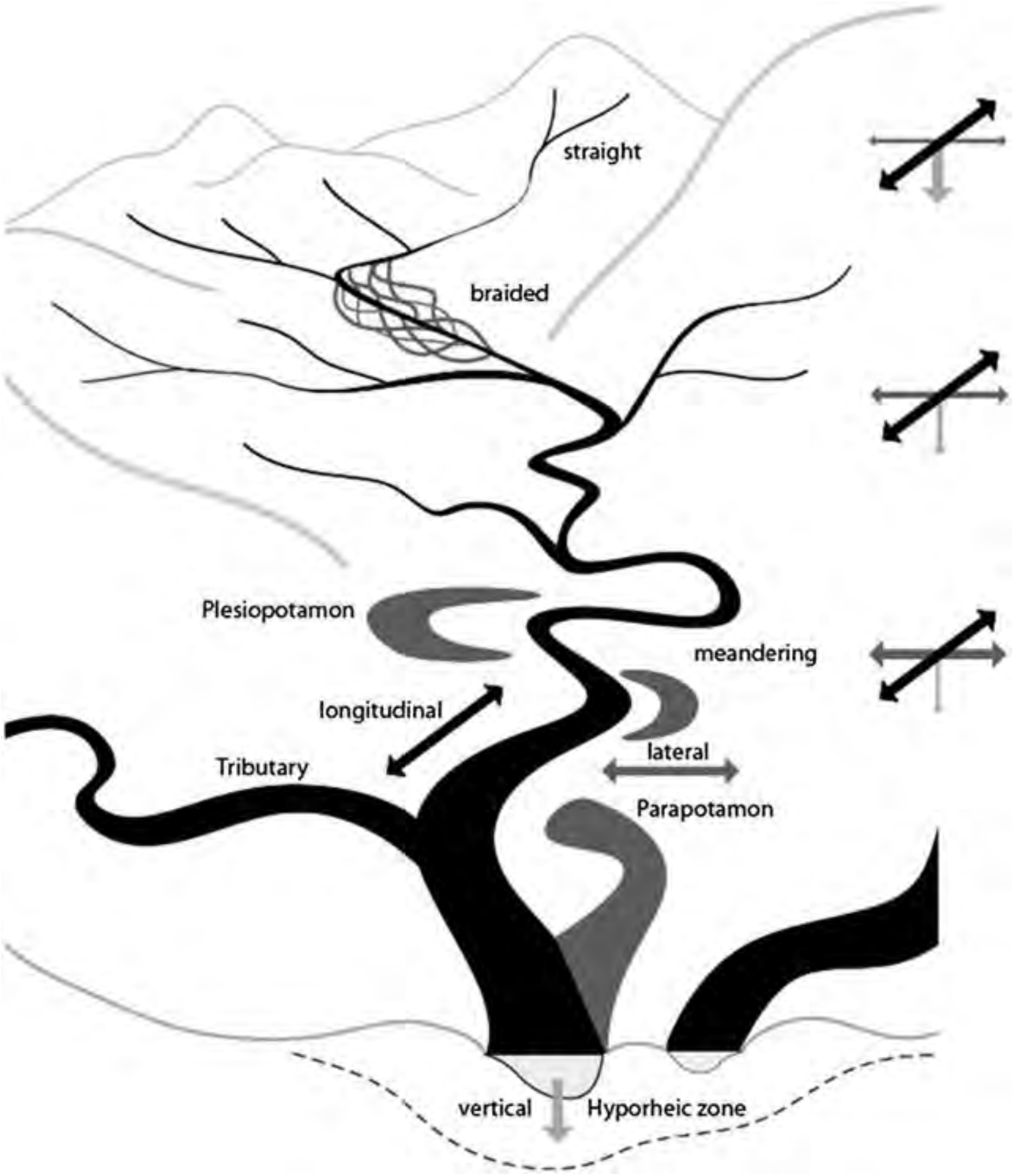
The four-dimensional river
© Macroecological Riverine Synthesis (MACRO) 2017

Longitudinal (upstream and downstream direction) – Lotic, or flowing water systems often experience structural changes between the source of the water and the end, or mouth of the system. We commonly recognize three zones: **headwaters, transfer zone, and depositional zone.**

> **Headwaters** - where flow is usually lowest in the system, it is the steepest, and erosions is greater than deposition of sediment.
>
> **Transfer Zone** – middle portion of the stream where it has usually flattened (to a degree), increased flow, and both deposition of sediment and erosion are occurring.

Depositional Zone – the downstream portion, where the flow is at its highest, but it has minimal slope, and generally the deposition of sediment is greater than erosion

Lateral (across channel, floodplains, and hillslopes) – Many streams have a channel, with the deepest part called the **thalweg**. Flooding is frequent on low floodplains but higher flood plains only flood occasionally (e.g., 100-year or every 500-years). Former floodplains that the stream no longer floods are called **terraces**. Other upland areas, and hillslopes, extend to the watershed boundary.



Longitudinal succession of the three spatial dimensions
© Seliger and Zeiringer 2018

Vertical (surface waters, ground water, and interactions) – Rivers and streams, and other water bodies, constantly interact with groundwater aquifers and exchange water, chemicals, and even organisms. Throughout its length, a stream will vary between areas where surface water leaks into the aquifer and areas where water is leaving where the stream will receive water from the aquifer.

Temporal (differences in time, from annual shifts in weather to long term evolutionary change) – Rivers and streams are constantly changing. The structure of flowing, or lotic systems, needs to always consider time as they are never permanent. Watershed managers must consider not only the watershed as it is structured in the present, but as it may change over time.

Lentic (Still) Waters

Canada is estimated to have over 2 million lakes, with ~110,000 located in Manitoba. Lentic, or still water, systems include lakes, ponds, and many wetlands. The structure of a lake has important impacts on its physical, chemical, and biological features. Many lentic, or still, systems have freshwater borides, but some may also have a varying level of salinity (e.g., Little Manitou Lake in Saskatchewan and Mahoney Lake, British Columbia). Most basin-type wetlands are also considered to be lentic waterbodies. Most lentic systems, like lakes and ponds, are almost always connected to streams, but not all streams are connected to lentic systems.

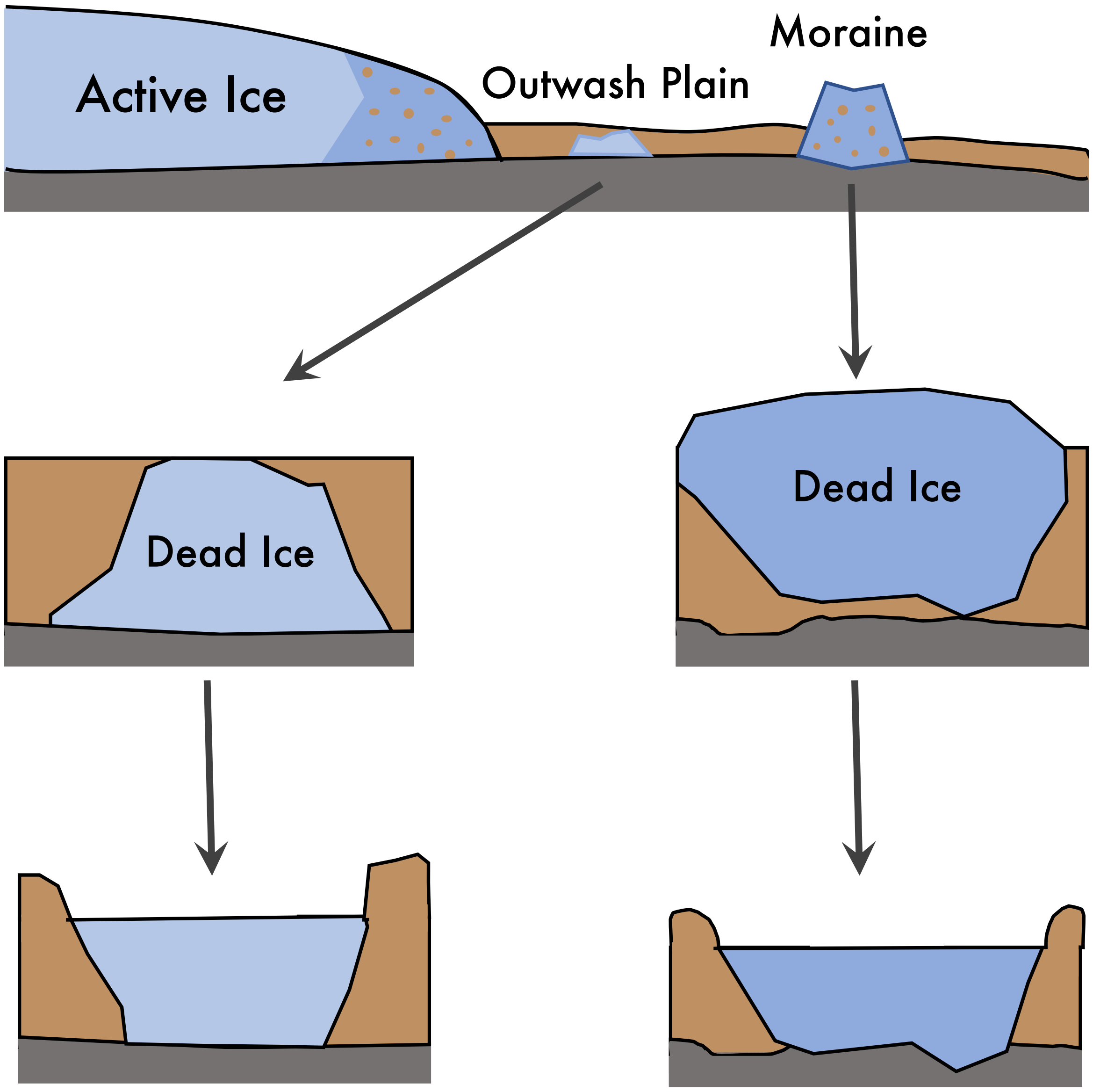
Formation of Lakes

The current chemical and biological condition of a lake depends on many factors, including:

- how it formed
- size and shape of the lake basin
- size, topography, and chemistry of its watershed
- regional climate
- local biological communities
- activities of humans

Glaciers formed lake basins by gouging holes in loose soil or soft bedrock, depositing material across stream beds, or leaving buried chunks of ice that later melted to leave lake basins. When these natural depressions or impoundments filled with water, they became lakes.

After the glaciers retreated, sediments accumulated in the deep parts of the lake through transport by streams and within-lake cycling of organic material. Lake sediment deposits provide a record of a lake's history.



Basic Functional Differences Between Streams and Lakes

Lake and stream dynamics are different due to differences in energy and how long water remains in one location, also known as water residence time. Streams primarily get their energy from the terrestrial environment and so they are much more dependent on the watershed where they are found. Although lakes are also dependent on their watersheds for energy, most of the trophic activity occurs within the lake. The species of animals and plants, as well as other organisms, differ between lakes and streams. The flowing water currents in streams and rivers impact the species that are found within these areas. The majority of primary producers and consumers found in streams and rivers are benthic organisms, as they will spend most of their time associated very closely with the substrate. In lakes, which may stratify and be limited in light and nutrients as you move through the stratifications, organisms may spend more time suspended within the water column.

Lakes	Streams
Water retained for extended period (days/months/years)	Water in transit almost immediately
Energy fixed primarily in lake	Energy fixed primarily in watershed
Most organisms suspended in water column	Most organisms near/on or in substrate

Upland Watershed Structure

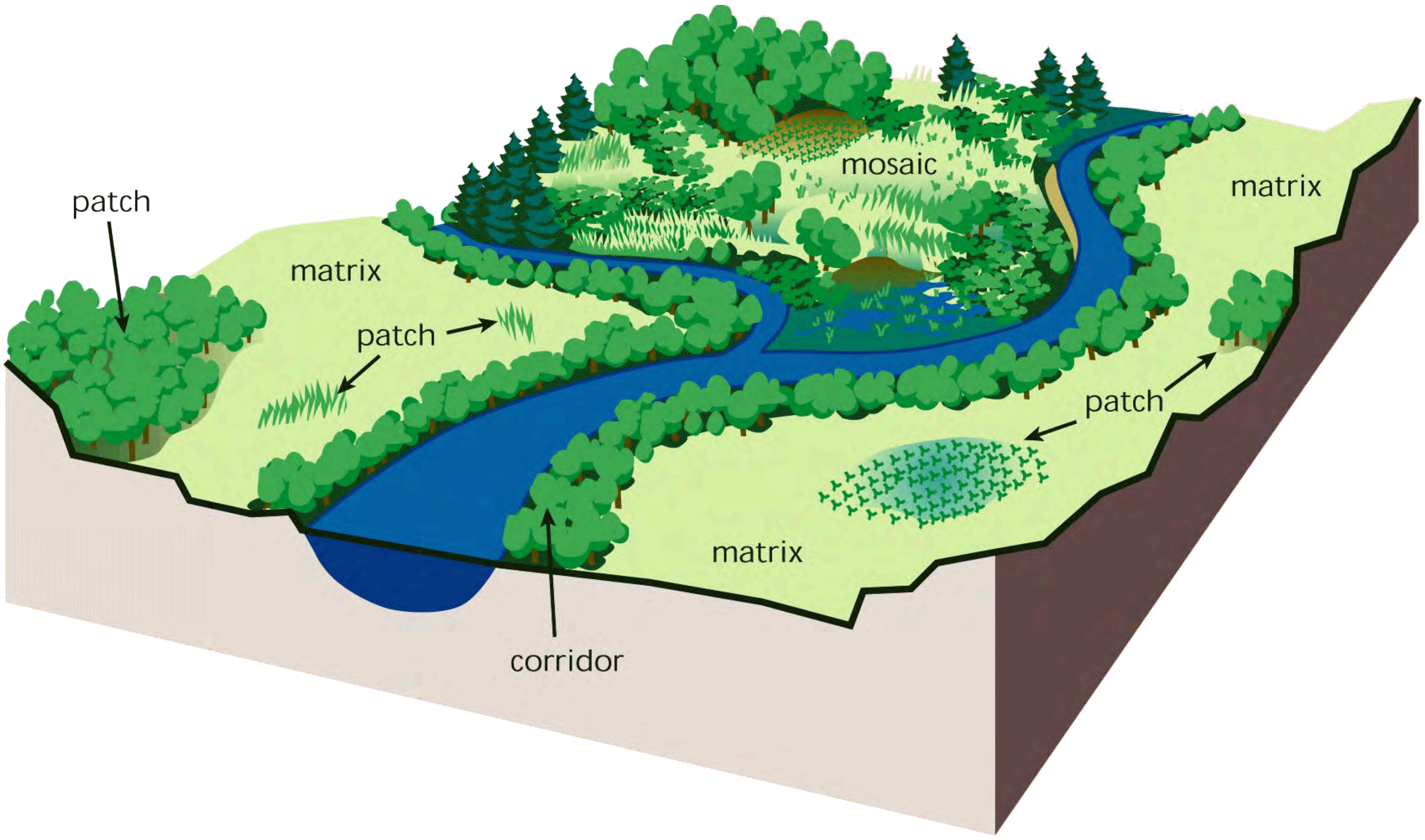
Upland watersheds can vary greatly in their physical form. The landscape pattern is the distribution of and variations in vegetation and land use within the watershed uplands. Variation in the landscape patterns have very significant influences on the condition of the water bodies they drain into.

LANDSCAPE PATTERNS

Landscape ecology is often described using three main terms: **matrix**, **patch**, and **mosaic**.

Matrix: dominant land cover (over 60%)
Patch: non-linear (straight) area that has less vegetation, and different from the matrix
Mosaic: collection of different patches but no dominant matrix (land cover)

Many landscape patterns are a combination of native vegetation communities, unvegetated areas, and a variety of land use patterns.



Spatial structure of a landscape

Landscape pattern change

Patches within a landscape can change over time, as can the entire landscape. Landscapes are constantly dynamic, as disturbances and various landscape processes alter these systems, as a shifting mosaic. Many landscapes have remained in a dynamic equilibrium. Although these landscapes are changing steadily from place to place, they maintain mosaic stability. For example, a forestry industry, that is well managed, would shift locations where mature forest is present, but at the same time maintain the relative proportions of forested and non-forested land in the area. Alternatively, a landscape may change towards a new composition and pattern (for example, through timber clearcutting, suburban development, abandoning developed areas, succession of agricultural lands into forests or grasslands, changes due to pathogens, fire, and/or climate change).

Vegetation and Land-Use Patterns

Vegetation Patterns

Vegetation in upland areas will vary spatially and follow a variety of biogeographical patterns based on climate, physiology, soils, disturbance regimes (e.g., fire), and their interactions. See *Forest and Plant Ecology Resource* for more details.

In vegetation communities a few species of plants will dominate and establish a structure and form that is characteristic to the community. In these communities, often there are a large number of less abundance organisms. As described in the *Forest and Plant Ecology Resource*. Regions of the earth have also been grouped based on the types of vegetation present, known as vegetation regions, or habitat types. The four major types are grasslands, tundra, desert, and forests. Shrublands are a fifth area, that are often just examined as the transition between forests and other regions yet have their own unique vegetative structure.

Land-use patterns

The landscape pattern and structure we see today is a result of human or anthropogenic activity. Watershed management, like most fields of environmental management, use land use types, patterns, and trends, in their planning. Maps often use the term **land cover** to describe the differences in landscape structure and pattern. Common land cover categories include:

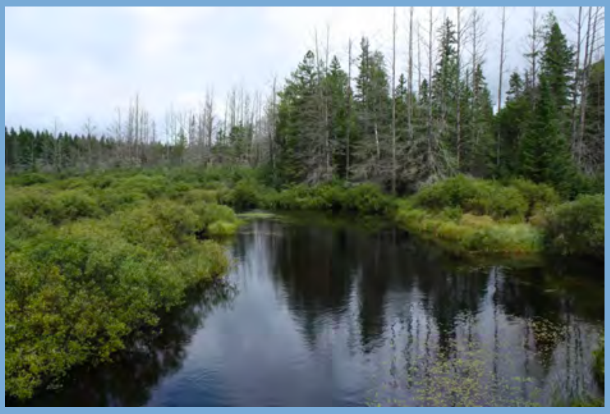
- Urban land (residential, commercial, industrial, mixed)
- Agriculture (crops, pasture)
- Transportation (roads, railroads, airports, port)
- Rangelands
- Silviculture
- Horticulture
- Mining or other natural resource extraction areas

Land use patterns, even those in watersheds, are often studied through GIS (Geographic Information System) data and maps. Anthropogenic, or human-dominated landscapes, are shifting mosaics just like natural landscapes.

Watershed Tour

The following section is from Ohio State University's Ohio Watershed Network (http://ohiowatersheds.osu.edu/resources/watershed-tour)

Headwaters



Here you will notice that we are at the highest point in the watershed where the water that falls on the land as precipitation begins its journey down the valley.

Headwater streams are many, but they are also the smallest streams in the watershed - some only a few inches wide, the largest only a few feet wide. The land here is often steep and the water may run fast, forming small waterfalls and pools. Headwater streams may form from surface runoff, melting snow, or groundwater that seeps out to the surface as springs.

Most of the water you will see later in the lakes and rivers downstream is the result of the collected water from hundreds and even thousands of small headwater streams. For this reason, what happens to and on the land surrounding the headwaters affects the quality of the rivers and lakes hundreds of miles away!

Middle Reaches

Moving farther downstream, you can see that many of the smaller headwater streams have come together, forming a wider, slower moving creek. Over time, the creek has cut into the banks, forming a more permanent stream bed. Notice that the terrain here is less steep, so there are few, if any waterfalls.

Along both sides of the creek you will see flat areas of land where the creek occasionally overflows. This flat area is called the floodplain, and when the creek overflows it dumps sediments from the water onto the floodplain, returning some of the eroded soil from the headwaters area back onto the land. Periodic flooding is a natural process in the life of the creek.

There the creek runs deep and slow, it forms pools where fish often congregate. Between the pools are shallow stretches called riffles where the water runs fast and turbulent over a gravel bottom. Certain kinds of small fish and insects have become specially adapted to the swift currents and gravel bottoms of the riffles.

Human activities here in the middle reaches can have a major impact on the water and its inhabitants. For instance, if livestock have access to the stream, they may accelerate the natural erosion of the stream bank, increasing the amount of sediments carried by the creek and changing the course of the stream.

In some areas, the stream channel has been straightened and widened, allowing the stream to flow unimpeded, thereby minimizing property damage from stream bank erosion and flooding. But alteration of the natural flow of the creek can also result in the destruction of important habitat for many species of fish and other aquatic life and can increase the risk of flooding downstream.

The Lake

Often times, a stream or creek will flow into a lake. There are three major kinds of "lakes" - lakes, ponds, and reservoirs. Generally, a pond is a body of water no larger than about ten acres in size, whereas a lake can be several hundred or thousands of acres in size - like Lake Erie.

A reservoir is a human-made lake, which may have been built for flood prevention or as a storage basin to provide water for human consumption and recreation.

All of Ohio's lakes have water flowing in and water flowing out, but the water tends to move very slowly once it enters the lake. Because of the higher retention time of water in a lake, sediments and many contaminants in the water tend to settle to the lake bottom.

As the sediments build up, the lake begins to fill in, becoming shallower over time. Activities in the headwaters and middle reaches that cause soil erosion will accelerate the buildup of sediments in the lake, as is happening in many lakes and reservoirs in Ohio. Many of these lakes would fill in completely over a short time, being replaced by a wetland or meandering stream, if the sediments weren't removed from time to time through a costly process called dredging.

Lakes are vulnerable to contamination because of what happens both in and around them. Development of the lakeshore can create pollution problems as fertilizers from lawns and sewage from septic tanks wash or seep into the lake. Recreational activities like boating can also add fuel, oil, and other toxic chemicals to the water. Many lakeside residents are coming together to encourage the adoption of best management practices to protect the lake's ecological integrity.

Wetlands

Wetlands come in many shapes and sizes, but, generally, when we talk about wetlands we're talking about a very shallow pond or lake.

So shallow, in fact, that much of the vegetation in the wetland emerges from the surface of the water. The water level in a wetland can vary greatly over a short period of time, making it difficult to define exactly where a wetland begins, and where it ends.

Wetlands are often likened to giant sponges, because the water that flows into a wetland is often stored for a long time in the soil and vegetation. For this reason, wetlands play a role in flood control and recharging groundwater aquifers.

Artificial wetlands like the one to the right are being constructed in some areas of Ohio, particularly where livestock are raised, because of their potential to filter out pollutants from contaminated water such as runoff from feedlots.

One of the greatest benefits of wetlands is the great variety of plant and animal life.

Fish, mammals, waterfowl, insects, songbirds, and any number of unique plant species can all be found in Ohio's wetlands. More than 90% of Ohio's wetlands have been drained or filled since European settlers first arrived. Laws now exist to protect our remaining wetlands, much remains to be done to protect this incredible natural resource.

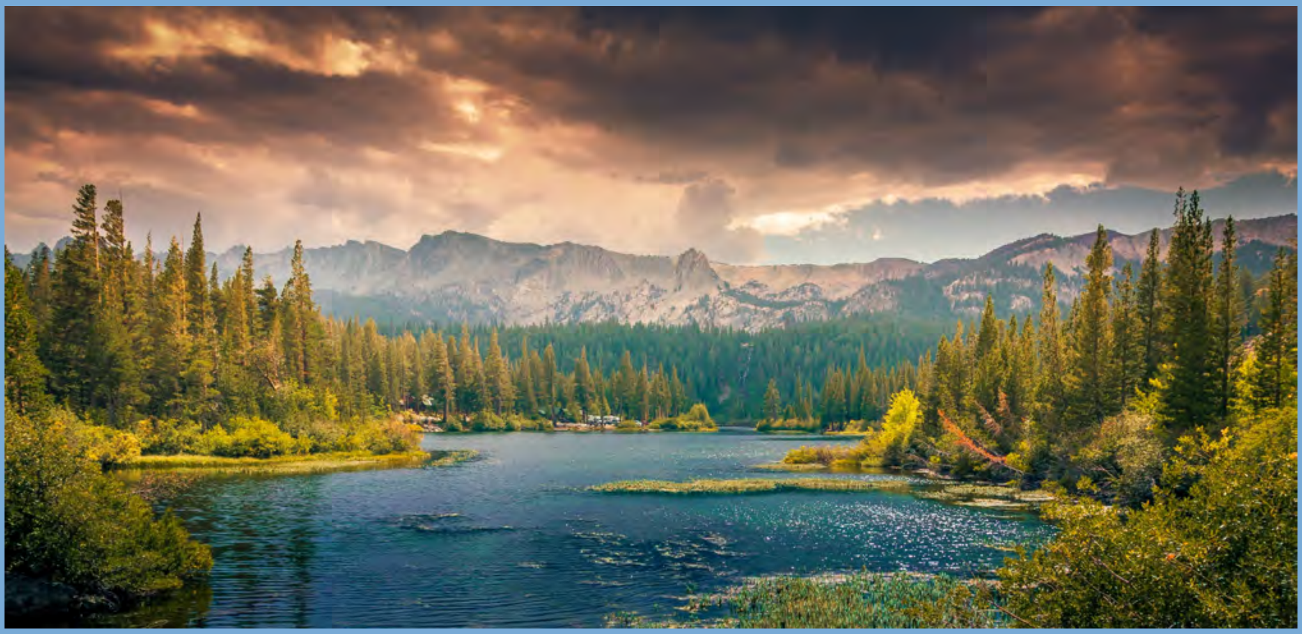
Mighty River

As we move downstream, more and more medium-sized streams have emptied into the main channel, contributing to the flow of what eventually becomes a river.

The channel flows wider and deeper flowing through a wide flat floodplain along the bottom of the river valley. Because the water runs more slowly here, some sediment settles out, forming a sandy or muddy substrate on the river bottom.

Eventually we reach the river's mouth, where it empties into yet another body of water, perhaps a larger river or a lake. For example, in Ohio all rivers and streams flow either into the Ohio River or Lake Erie.

Any sediments, debris, or contaminants still carried by the river, even from the farthest reaches of the headwaters, will be emptied into the receiving waters. As a result, what we find, or don't find in our major rivers, Great Lakes, and coastal areas will provide us with clues about the health of all of our nation's diverse ecosystems.



DRAINAGE PATTERNS

Drainage patterns are created by stream or river erosion over time. They often reveal characteristics of the geological structure of the landscape. Drainage patterns are often directed by the topography (the arrangement of natural and artificial physical features of an area) of the land, bedrock composition, and the land slope or gradient.

The main types of drainage patterns:

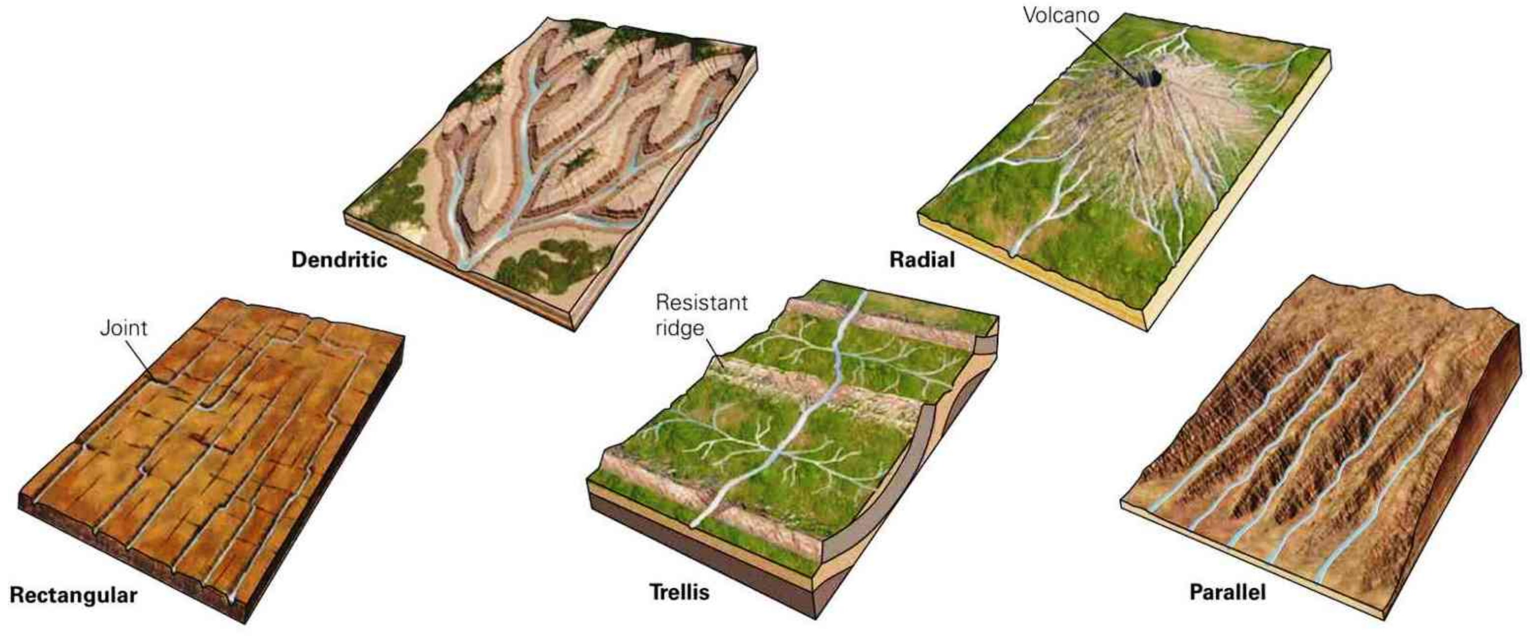
Dendric patterns – the most common type of pattern found in areas where the rock beneath the river or stream bas no particular structure and can be eroded easily in all directions. Examples include granite, volcanic rock, and sedimentary rock. Most locations in British Columbia, the prairies (Saskatchewan and Manitoba), and the Canadian shield.

Trellis patterns – these patterns develop where sedimentary rocks have been folded or tilted. These areas have then eroded to varying degrees. The Rocky Mountains in British Columbia and Alberta have this type of drainage pattern.

Rectangular patterns – these patterns develop in areas with little topography and systems of bedding plan, fractures, or faults that form a rectangular network. This type of drainage pattern is rare in Canada.

Parallel patterns – a pattern of rivers that is caused by steep slopes, that form where there is a strong slope to the surface. Due to the slopes, the streams are swift and straight with very few tributaries. All of these streams flow in the same direction.

Radial patterns – this pattern of drainage has streams radiating outwards from a central high point, like a volcano.



Deranged drainage systems occur when there is no coherent pattern to the rivers and lakes. These patterns are observed in areas where there has been a lot of geological disruption, like the Canadian Shield. The topsoil was scraped off of the bare rock during the most recent ice age.

FRESHWATER ECOSYSTEM INTEGRITY

Freshwater ecosystems share a number of important features, but also will differ greatly from one another depending on a variety of factors including, type, location, and climate. All water systems, including lakes, wetlands, rivers, and ground waters connecting them all need water within a specific range of quality and quantity. As all freshwater ecosystems are dynamic, they require a range of natural variation and/or disturbance to maintain resilience and viability. Flows will vary year to year, and season to season. The variation in the rate and timing of water flow will strongly influence the size of native plant and animal populations. It will also impact the age structure, the presence of rare or highly specialized species, species interactions with their environment, and other ecosystem processes. Periods and irregular occurrences of water flow can influence water quality, physical habitat conditions, physical connections, and energy sources in freshwater ecosystems. These systems have evolved to experience changes and patterns of variability in their hydrology.

Freshwater ecosystem structure and function are strongly connected to the watersheds in which they occur. Water moving through the landscape towards the oceans moves in three dimensions, surface waters to ground water, linking upstream to downstream, and stream channels to floodplains and riparian wetlands. Any material that is picked up along the way, will eventually make its way into freshwater bodies, such as rivers, lakes, and wetlands. Freshwater systems are therefore greatly influence by what happens on the land, including human development and activities.

Five dynamic environmental factors are responsible for most of the function and structure of freshwater ecosystems, although how important they are will depend on the ecosystem type. It is essential to consider and integrate all five factors together when evaluating freshwater ecosystem integrity. The interactions of these factors in time and space will impact the dynamic nature of the ecosystem:

Flow pattern

The rates and pathways that rainfall and snowmelt use to enter and circulate within river channels, lakes, wetlands and ground waters. It also determines how long water is stored in the ecosystem.

Sediment and organic matter

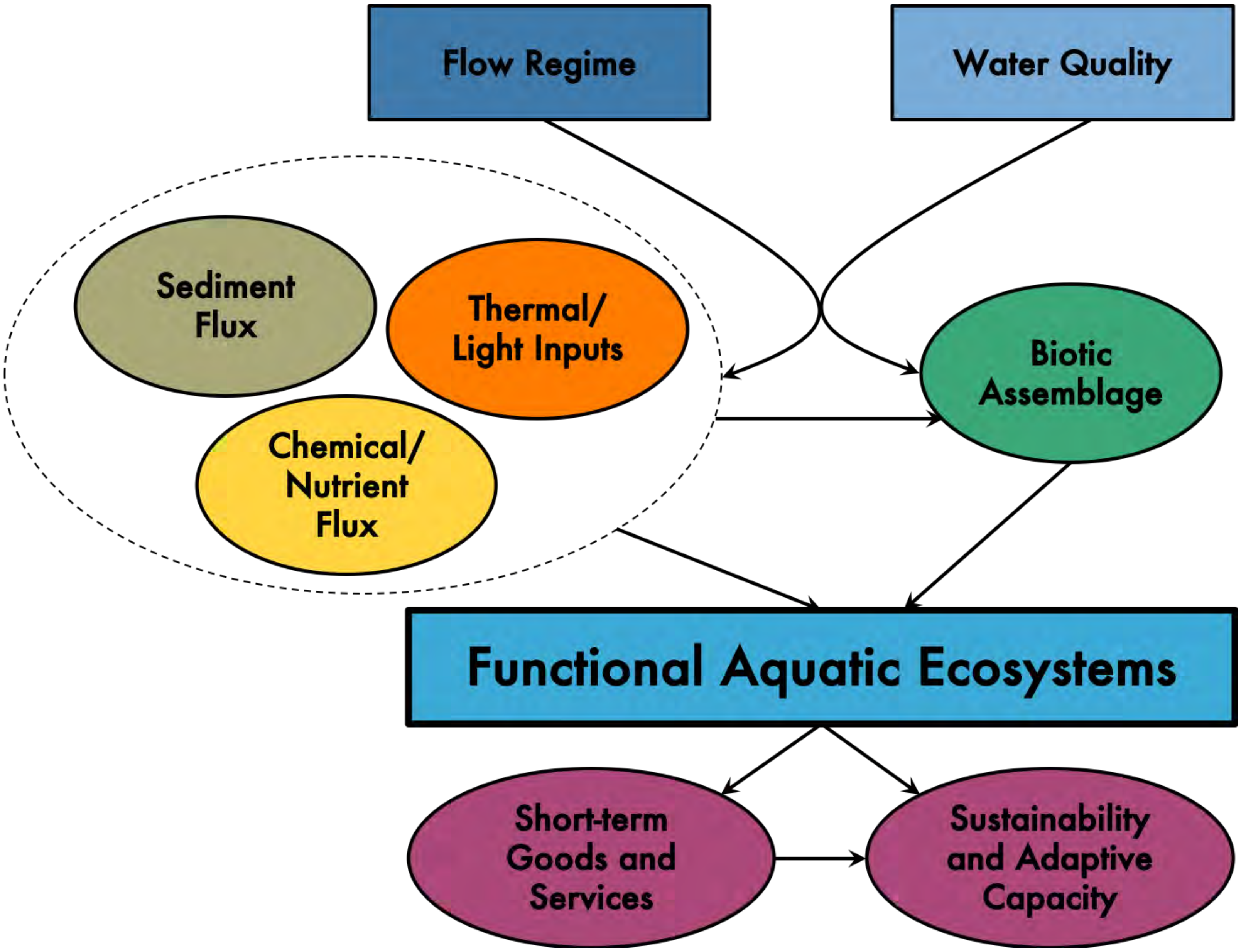
Sediment and organic matter inputs will provide the raw materials that create the physical habitat structure, substrates, refugia, and spawning grounds. It also will supply and store nutrients that are needed to sustain aquatic animals and plants.

Temperature and light characteristics

Characteristics, like temperature and light, regulate metabolic processes, activity levels, and productivity of aquatic organisms.

Chemical and nutrient conditions

The nutrient and chemical conditions of a water body regulate the pH, water quality, and the animal and plant productivity.



Conceptual model of major forces that influence freshwater ecosystems
© O'Keefe et al. 2020, US EPA

Animal and plant assemblages

The species assemblage of both animal and plants will influence community structure and ecosystem process rates.

In undisturbed freshwater ecosystems, all of these factors vary annually within defined ranges, tracking changes in climate and day length. Freshwater species and ecosystems have evolved to adjust and accommodate these annual cycles. They have also evolved strategies for surviving extremes in hydrology caused by floods and droughts, or periods where conditions exceed the normal annual highs or lows in temperature, flow, or other factors.

Flow Patterns

A description of the natural or historical flow patterns of streams, rivers, wetlands, and lakes, is key to a proper evaluation of the characteristics for its healthy function. Specific aspects of these patterns are critical for biological productivity regulation (e.g., algal and phytoplankton growth) and biological diversity. Aspects include base flow, frequent or annual floods, rare and extreme flood events, annual variability, and flow seasonality. See the definitions of each below.

Flow Pattern Definitions

From O'Keefe et al. 2020. Introduction to Watershed Ecology, U.S. Environmental Protection Agency

Base flow conditions characterize periods of low flow between storms. They define the minimum quantity of water in the channel, which directly influences habitat availability for aquatic organisms as well as the depth to saturated soil for riparian species. The magnitude and duration of base flow varies greatly among different rivers, reflecting differences in climate, geology, and vegetation in a watershed.

Frequent (that is, two-year return interval) floods reset the system by flushing fine materials from the stream bed, thus promoting higher production during base flow periods. High flows may also facilitate dispersal of organisms both up- and downstream. In many cases moderately high flows inundate adjacent floodplains and maintain riparian vegetation dynamics.

Rare or extreme events such as 50- or 100-year floods represent important reformative events for river systems. They transport large amounts of sediment, often transferring it from the main channel to floodplains. Habitat diversity within the river is increased as channels are scoured and reformed and successional dynamics in riparian communities and floodplain wetlands are reset. Large flows can also remove species that are poorly adapted to dynamic river environments such as upland tree species or non-native fish species. The success of non-native invaders is often minimized by natural high flows, and the restriction of major floods by reservoirs plays an important role in the establishment and proliferation of exotic species in many river systems.

Seasonal timing of flows, especially high flows, is critical for maintaining many native species whose reproductive strategies are tied to such flows. For example, some fish use high flows to initiate spawning runs. Along western rivers, cottonwood trees release seeds during peak snowmelt to maximize the opportunity for seedling establishment on floodplains. Changing the seasonal timing of flows has severe negative consequences for aquatic and riparian communities.

Annual variation in flow is an important factor influencing river systems. For example, year-to-year variation in runoff volume can maintain high species diversity. Similarly, ecosystem productivity and food-web structure can fluctuate in response to this year-to-year variation. This variation also ensures that various species benefit in different years, thus promoting high biological diversity.

The factors are also important for assessing lake and wetland integrity as flow patterns and **hydroperiod** (seasonal fluctuations in water levels) impact water circulation patterns and the water bodies renewal rates. They will also impact the species and abundance of aquatic vegetation, including reeds, grasses, and flowering plants. Additionally, the flow pattern of a lake, wetland, or stream influences the algal productivity and is important to consider when determining levels of nutrient runoff (phosphorus and nitrogen) from the surrounding landscapes that are tolerable for the normal functioning of a system.

Water can be diverted away or into a waterway. This can significantly change flow and water levels. For example, storm water drains and pipes discharge water and its associated contaminants into a waterway, thereby increasing flow and turbidity. Alternatively, changing the direction of a waterway may direct water away from its natural flow which may reduce water levels and significantly alter a waterways natural characteristics. Diverting water can permanently impact on water quality and natural communities.

Diverting water permanently or temporarily, e.g., in river or stream beds, to install sediment control, storm water devices or when realigning a waterway, can significantly affect the natural character of a waterway and the surrounding habitat. Water can be diverted using in-stream barriers such as dams, weirs, culverts, canals, and pipes. Generally speaking, dams, which hold back flows for release when they are more useful or less destructive, and diversions, which redirect the resource to where it is more useful.

A dam is a barrier that stops or restricts the flow of water or underground streams. Reservoirs created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability.

Generally, rivers are dammed to create reservoirs for power production, downstream flood control, recreation, or irrigation. Canada ranks as one of the world's top ten dam builders.

Previous anthropogenic (human) changes to river flow have rarely taken into account the ecological consequences of the action. Dams can impact the water quality and biotic community of a river system. The land behind it is flooded which may mean the loss of valuable wildlife habitat, farmland, forests, or town sites. Additionally, accumulation of sediments in the reservoir can have a negative impact on water quality by creating increased concentrations of harmful metal and organic compounds in the reservoir. If vegetation is not removed behind the dam before flooding, other problems can occur. The eutrophication process may occur at a faster rate and adversely affect the water quality.

Channelizing streams

When a stream is prone to flooding, or to meandering out of control and across property lines or roads, we often **channelize** it. We may dry up whole sections of stream in order to bulldoze it into a tidy, straight line of water. We may try to protect ourselves from its unruly behaviour by lining the stream's banks with concrete or riprap. This kind of channelization leads to loss of both stream and riparian habitat. It also increases the destructive potential of the river. A channelized stream becomes poor in nutrients and habitat. Without periodic flooding, its riparian zone is starved of water and nutrients. Stream inhabitants depend on the riparian zone for food, shade, and debris. Channelization creates artificial river banks without variation, while stream inhabitants depend on natural variations such as backwaters, riffles, embayments, and large woody debris for shade or warmth, cover, protection, and food.

Ironically, the more you try to channelize a river, the more out of control it becomes. Erosion, a minor irritant before, threatens property, buildings, and roads. Flooding becomes more catastrophic when streams are channelized. Water gathers energy as it flows downhill. When a stream meanders, it creates banks. The water then pushes against the banks, and swirls in eddies. In both cases, the energy of the flowing water is decreased. When a stream is channelized, however, there is nothing to prevent it from gathering more and more destructive energy as it flows downhill. Secondly, a healthy floodplain acts as a sponge, soaking up floodwaters, while channelized rivers simply forward the extra water downstream until it overwhelms dams, dikes, or walls. Finally, when rivers are channelized, people are encouraged to live on floodplains, risking lives and property in the event of a catastrophic flood. The inevitable response to catastrophic flooding is, unfortunately, to increase channelization, which leads to even more catastrophic flooding.

Sediment and Organic Matter Inputs

The movement of sediments and addition of organic matter into river systems are important components of habitat dynamics and structure. Organic matter inputs include seasonal runoff and debris (e.g., leaves and decaying plant material) from terrestrial ecosystems) into the watershed. The organic matter that comes from the terrestrial is a very important source of energy and nutrients, and woody materials that fall into the water provide important substrates and habitats for aquatic species, especially in rivers and streams.

Sediment (all but the finest material) in lakes and wetlands will fall permanently to the bottom, eventually filling the systems. The species in the freshwater ecosystems, such as invertebrates, algae, bryophytes, plants, fish and bacteria, that live on the bottom (benthic) zone, are highly adapted to their specific sediment and organic matter conditions. They will not persist if there are changes to the type, size, or frequency of sediment inputs.

Anthropogenic development has altered natural rates of sediment and organic matter inputs into freshwater ecosystems, both increasing and decreasing rates in different areas. For example, poor agricultural, logging, mining, or construction practices can lead to higher rates of soil erosion. Additionally, in some areas small streams and wetlands have been completely removed or re-routing. Dams are also known to alter sediment flows in both reservoirs behind the dams (increasing sediments) and the streams below (decreasing sediments). Other changes, like channel straightening, overgrazing of river and stream banks, and clearing of riparian plants will also reduce organic matter inputs and often can end up increasing erosion.

Temperature and Light

Energy, light and heat, properties of water bodies are strongly impacted by topography and climate, as well as other waterbody characteristics. The chemical composition of a water body, suspended sediments, and algal productivity are all influenced by light and thermal energy (heat). Most aquatic species have evolved to use one of the more unique qualities of water, its heat capacity. Water has the unusual ability to absorb thermal energy (heat) with only minimal changes in temperature. Many fish, amphibians, and marine mammals require a consistent water temperature and has a restricted range of temperatures that they can withstand. As seasons change, water temperatures will change much more slowly than air temperatures, which is easier on animals. If temperatures change too rapidly, aquatic animals can suffer thermal shock, leading to injuries or death. Further, it can make species more vulnerable to pathogens and subsequent disease. Additionally, particular life stages of animals may be more sensitive to sudden temperature changes. The temperature of water directly controls oxygen concentrations, metabolic rate of ectotherm species, and ecosystem processes such as growth, maturation, and reproduction.

Temperature cycles influence the fitness (survival and reproduction) of both aquatic plant species and animals. The temperature will influence the distribution of species and the community structure, for example how species are distributed within the water body from season to season. Specifically, in lakes solar energy absorption and heat dissipation are critical to temperature gradient development between the surface and deeper water layers, as well as water circulation patterns. For more detailed information, see *Aquatic Ecology Resource*.

Nutrient and Chemical Conditions

Nutrient and chemical conditions reflect climate, bedrock, soil, vegetation types, and topography. Water conditions can range from clear, nutrient poor rivers and lakes (e.g., oligotrophic) to more nutrient rich waterbodies (e.g., eutrophic) in catchments with organic matter-rich soils, or limestone bedrock. The regional diversity in watershed characteristics helps sustain high biodiversity. Humans actions can lead to excess orthophosphates reaching water systems (eutrophication). The use of manufactured substances that contain phosphates, such as fertilizers, detergents, and industrial wastes, can contaminate water bodies. Human and animal wastes can also contain high levels of phosphates and enrich water bodies.

Plant and Animal Assemblages

Physical characteristics of habitats, including aquatic habitats, impact the types and species found within an area. Organisms are directly impacted by the environmental around them, including nutrient concentrations, temperature, water flow, and shelter. For an animal or plant to be found within a particular habitat, it needs to be able to survive the conditions, find shelter and space, and have nutrients available. Further, the species within an area can also impact aspects of their environment. For example, beaver damns can change water flows in the environment, and zooplankton can change nutrient availability.

Biotic characteristics of the habitat also may impact the species found within it. The interactions between species will impact the type of species and number of each species within each aquatic ecosystem. Competition for resources, such as food or habitat, predation, and parasitism, all impact species abundance and diversity. Aquatic ecosystems often contain a variety of species, including (but not limited to), bacteria, viruses, fungi, protozoans, insect larvae, snails, worms (wide variety), microscopic plants, zooplankton (very small animals), plants such as cattails, bulrushes, seaweed, grasses, reeds, and algae, larger animals such as fish (e.g., catfish, arctic char, tuna, sharks), amphibians (e.g., frogs), reptiles (snakes, crocodiles, birds etc.), and mammals (e.g., beavers, muskrat, seals). The species found in each system varies depending on both **biotic** and **abiotic** conditions, as described above. Often **habitat** conditions may be quite unique to each type of ecosystem leading to a unique assemblage of species found within the system. For example, many rivers are relatively oxygen-rich and fast-flowing compared to lakes habitats. The species **adapted** to these particular river conditions are often rare or absent in the still waters of lakes and ponds.

“It’s at the very core of everything”
The significance of Canada’s wild rivers

The following section by Brandon Wei, Canadian Geographic, 2019

www.canadiangeographic.ca/article/its-very-core-everything-significance-canadas-wild-rivers

Only a third of the world’s rivers longer than 1,000 kilometres remain free-flowing. In North America, 70 per cent of those are in Canada. Meet some of the people who want to keep it that way.

Sixty years ago, British Columbia’s Bridge River Valley was known as the “land of plenty” to the St’át’imc people. Home to deer, moose, and Chinook salmon, the valley — located in the province’s southwest, a few hundred kilometres north of Vancouver — sustained several First Nations communities for thousands of years.

In 1959, that natural abundance was washed away. Two massive dams were constructed as part of the Bridge River Power Project, diverting the flow of Bridge River and flooding the valley.

“We had everything up there,” says Gerald Michel, land and resource coordinator for the Xwisten people who live along Bridge River. “We even had caribou and elk, but the elk have been hunted out and the caribou are long gone.”

The creation of new reservoirs blocked the migration corridors of the native ungulates, forcing them onto highways, where they are frequently struck and killed by vehicles, Michel says. And high-release flows from Terzaghi Dam, which occur when power demand is high or to regulate water levels downstream or in the reservoirs, are playing havoc with fish populations.

“[The flows] are killing fish and destroying fish habitats,” says Michel. “After 2016, we’ve noticed we’ve lost 70-80 per cent of our small fishes. They’re flushed right out of the system.”

Free-flowing Rivers under threat

The deteriorating health of the Bridge River and the surrounding ecosystem is just one example of what can happen when a river's course is manipulated by human activity, particularly power generation.

A landmark study published last month found that only one-third of the world's rivers longer than 1,000 kilometres remain free-flowing. In North America, more than 70 per cent of those rivers are in Canada.

Bernhard Lehner, a co-author on the study and an associate professor of global hydrology at McGill University, says infrastructure is the main culprit — with hydroelectric dams being the most problematic.

"They block the flow of the river," says Lehner. "Fish can't get through. Other species can't get through. Even plants that disperse along rivers when their seeds are carried with the flow can be stopped [by dams]."

Free-flowing rivers prevent the buildup of pollutants in habitats, deliver nutrients and sediment to estuaries, and are crucial to mitigating the effects of climate change, says Heather Crochetiere, a freshwater specialist at World Wildlife Fund Canada.

"Intact ecosystems are better able to adapt to changes in temperature and flow levels," she says. "When rivers are barrier-free, they act as natural corridors for fish and other species to relocate to conditions that may be more suitable for their survival."

Crochetiere and Lehner are among a growing number of experts who are calling into question the "cleanliness" of hydropower as an alternative to fossil fuel power generation. With some 3,700 hydropower projects either planned or already under construction worldwide, Lehner says it's time to reignite the conversation over which renewable energy sources are best for people and the planet.

"Our goal is not to say 'Stop hydropower.' In some places, there might be alternatives: solar power, wind," says Lehner. "We just want to shed some light on the fact that hydropower isn't perfect."

The “people of the Nass River”

Andrea Reid is less equivocal. A fisheries scientist and citizen of the Nisga’a Nation, she doesn’t view hydropower as clean energy, given the documented tendency of projects to displace communities and do irreparable damage to ecosystems.

“In many cases, it has eroded the places [communities] used to call home,” she says. “They can’t even live in those places anymore because they’ve been flooded out.”

Reid’s research is focused on the Nass, Fraser and Skeena Rivers — B.C.’s most productive salmon-bearing rivers — and highlights the huge differences in the health of those watersheds.

The Fraser River, which has been dammed along a few of its tributaries and is therefore shallower in its lower reaches, now becomes a lot warmer in the summer compared to the Nass and the Skeena — a trend which is worsened by climate change. This can seriously jeopardize salmon, which are cold water animals, she says.

The Nass River, which flows southwest from the Coast Mountains to Nass Bay by the Pacific Ocean, remains one of B.C.’s last near-pristine river systems and is a fundamental part of the Nisga’a Nation’s identity.

“The word ‘Nass’ is actually a Tlingit word that means ‘guts’ because of its food capacity. The Nisga’a are the ‘people of the Nass River,’” says Reid. “It’s tied to our origin stories. There are water ceremonies that are practiced. There are ceremonies around the first salmon to return. It’s at the very core of everything.”

Last summer, Reid spoke with elders across B.C. about the significance of Pacific salmon. What they ended up sharing, however, went much deeper.

“It was about fish, but it was also about the river and people’s connection to it,” says Reid. “Some elders were brought to tears talking about how they used to be able to drink directly from the river, and now they never can. Some even feel compelled to wash their hands after they touch the river, concerned over what’s in the water.”

Reid says she understands the important role hydropower can play in supplying urban centres with an alternative to more polluting forms of energy, but that too often, projects are approved without a full understanding of their potential impact.

"They're not assessed in terms of the environmental impacts of, if we add this dam to this system, and there are already five dams in that system, what that's going to do to the totality of the environment," she says.

Guardians of the Liard

Crochetiere says that a challenge to making informed water management decisions is the lack of data on Canadian watersheds. Many of Canada's wild rivers are extremely remote, which makes consistent monitoring and reporting difficult.

One such data-deficient river is the Liard. Flowing more than 1,200 kilometres from the Yukon, across northern B.C., to Fort Simpson in the Northwest Territories, it is Canada's longest wild river.

Wild rivers are rivers that remain relatively unaffected by human activity. For the Kaska Dena people, who have lived along the Liard for thousands of years, it's important that the Liard maintains this status.

In 2015, the Kaska Dena First Nations launched their Dane Nan Yế Dāh Land Guardian program, which aims to collect data on wildlife, address pollution concerns, and coordinate with hunters to protect significant cultural-use areas within their territory.

"We started the program just from complaints coming in: animals being poached, finding wasted meat, the influx of hunters," says Tanya Ball, traditional knowledge coordinator and full-time Guardian with the community of Lower Post in northern B.C.

Last fall, WWF Canada and Living Lakes Canada helped the Kaska Guardians expand their project by starting a freshwater monitoring program on the Liard and some of its tributaries.

Part of the program included training in sampling benthic invertebrates: organisms that live in or on sediment at the bottom of freshwater bodies and are an indicator of of a river's health, Crochetiere says.

Living Lakes Canada led the training in benthic sampling with help from WWF Canada, who gave technical advice and helped the Guardians identify the exact sites they wanted to monitor.

Ball says they've since installed gauges that measure water levels in the Blue River and the Dease River, the latter of which drains into the Liard.

And while the Guardians are still waiting for the lab results from their benthic sampling, Ball says the species they found — such as caddisflies, which are sensitive to poor water quality — indicate the water isn't polluted. The Guardians plan to do more invertebrate sampling this August.

"We want to create our own baseline studies of the rivers and their tributaries in our area," says Ball, emphasizing the significance it holds for her community.

"We live and hunt along its shores. We depend on it for sustenance. And we haven't had to worry about pollution or degradation of the area — at least, as of yet."

Left to right: James Malone, Raegan Mallinson, Catherine Paquette, Vanessa Law, and Corrine Porter working in the Liard. (Photo: Heather Crochetiere)

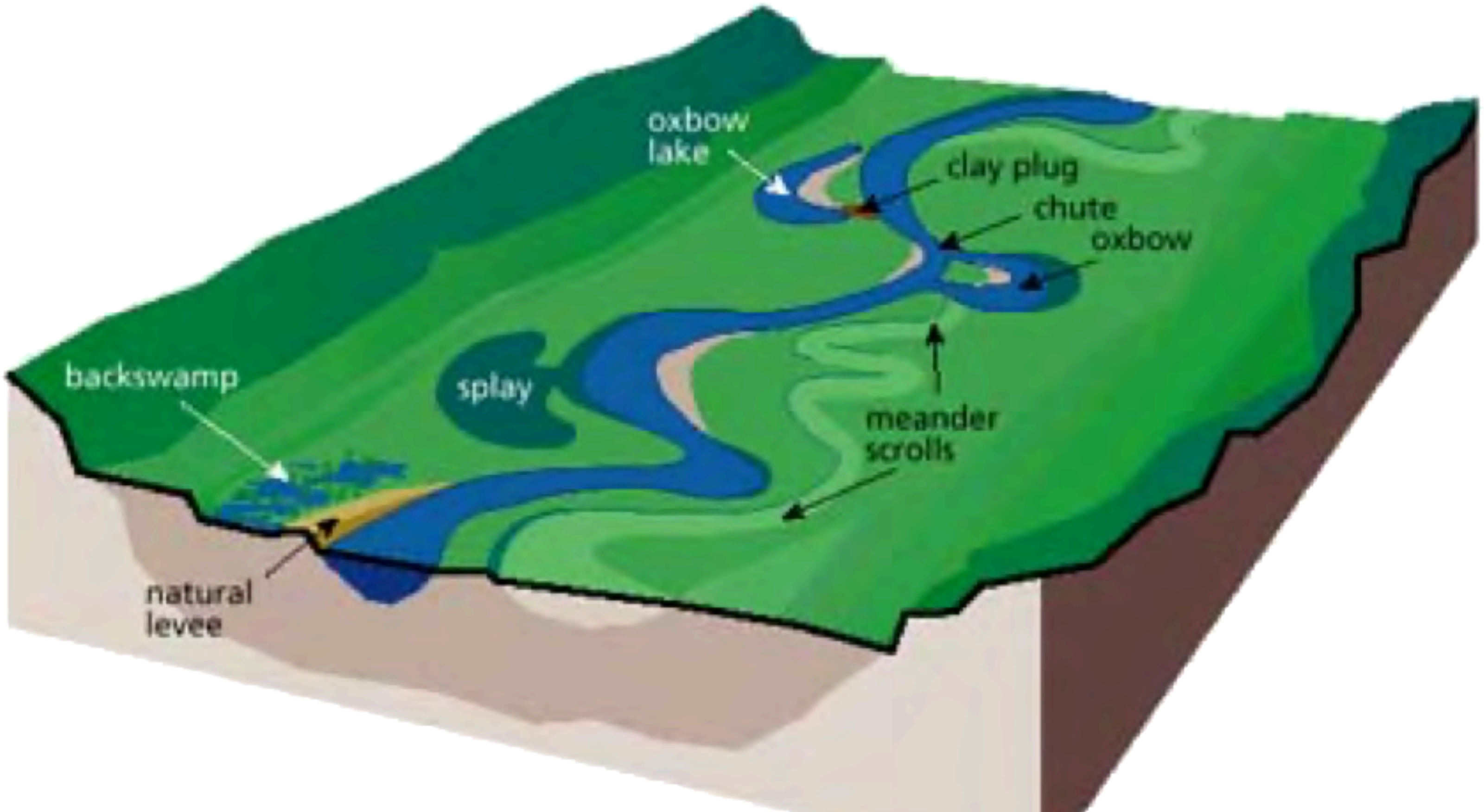
WATERSHED FUNCTIONS

One of the main functions of a watershed is to temporarily store and transport water from the land surface to the water body and ultimately onward to the ocean. Further, watersheds and waterbodies also transport sediment and other materials, energy, and many types of species.

Transport and Storage

A number of terms are used to describe how matter moves through a watershed. **Availability** is the presence of an element in the system and the usability of the element. For example, nitrogen may be plentiful in the form of a gas but is not available for most aquatic organisms in this form. **Detachment** is the release of matter from a its attachment point and its ensuing movement. **Transport** is the movement of material through a system, often most evident in stream channels. **Deposition** is the endpoint in the cycle. **Integration** is the assimilation of matter either into a site and organism following the matter's deposition.

A watershed collects and routes precipitation, but the transportation and storage of the water involves a complex mix of smaller processes. First, the precipitation interacts with vegetation. Trees and other vegetation are responsible for the inception and detection of some of the rainfall, eventually leading to evaporation and slowing the precipitation down,



improving groundwater infiltration. When precipitation accumulates faster than infiltration occurs, or soil becomes saturated, overland flow will occur, and over a longer time period drainage networks will develop. Water that flows consistently through a channel will impact and shape the channel development and morphology.

Finally, one of the major functions of watersheds is to collect and transport sediments. The transport of sediments and their storage is a complex network of smaller watershed process and is connected to water transport and storage. Erosion and deposition are the most common sediment related processes, but transport and storage also play a role in soil development in the longer term.

Erosion and Sedimentation

Rivers can move large amounts of material across the landscape. Any material that can be dislodged can be transported, such as silt, sand, and soil. Collectively, this material is called **sediment**. Material present in the water column is called **suspended sediment**, while materials deposited on the bottom of a water body are simply called **sediment**. Sediment is picked up from the landscape (**erosion**), **transported** by the stream, and ultimately deposited in an area with slower flow where the sediment is no longer able to stay in suspension (**sedimentation**), such as a lake or ocean. Sediment may also be deposited in a slower-flowing section of the stream. **Fluvial sediments** are those which have been eroded, transported, and deposited by flowing water.

Natural erosion takes place slowly, over centuries to millennia. Streams may also experience accelerated erosion due to human activity, such as digging along banks, removal of riparian vegetation, etc.

Transportation of sediment across the landscape begins at a very small scale at the top of the watershed where falling raindrops cause a phenomenon called **sheet erosion**. As water droplets run downhill, they pick up sediment and carry it to small streams, which carry it further down the watershed. The greater the discharge of a stream, the higher the capability there is for sediment transport.

Sediment comes to rest when there is not enough energy to transport it further, and the process of deposition is called **sedimentation**. **Depositional areas** occur as newly deposited material on a flood plain, sand/silt bars and islands in stream channels, and deltas in places where streams enter lakes and oceans. Substantial deposits may or may not be visible, depending on the amount of sediment transported.

The presence of suspended sediment directly affects stream communities in a variety of ways:

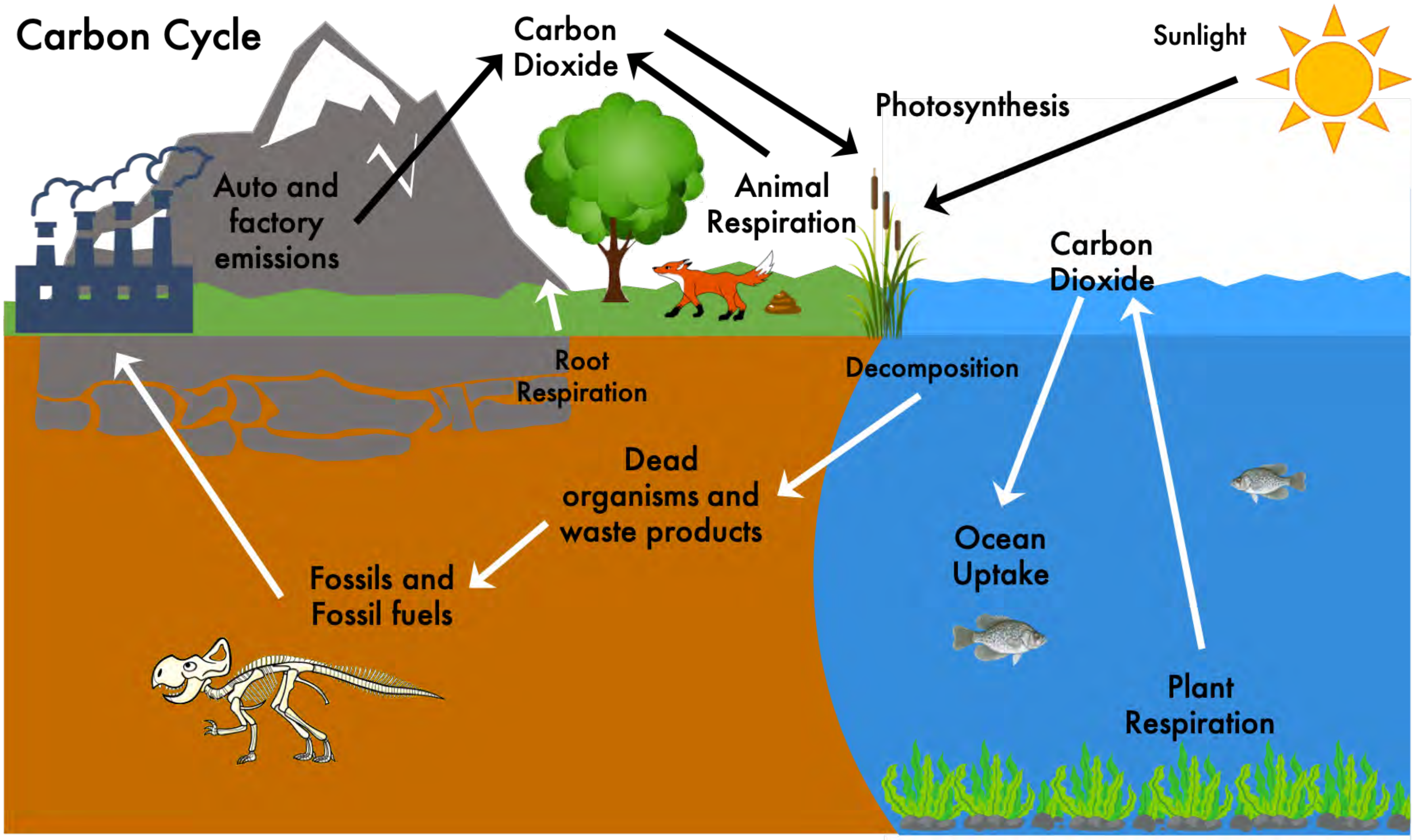
- decreases light penetration into water
- erodes the protective mucous covering the eyes and scales of fish, making them more susceptible to infection and disease
- particles absorb warmth from the sun and increase water temperature.
- high concentrations of suspended sediment can dislodge plants and sedentary organisms
- toxic chemicals can become attached (adsorbed) to sediment particles and transported to/deposited in other areas.
- Settling sediments can bury and suffocate fish eggs.

Cycling and Transformation

Watersheds also function in cycling and transformation of materials. Numerous resources, including water, are constantly cycling through watershed. Their interactions drive countless other watershed functions. Nutrients are an essential part of the cycle of life. As part of biosynthesis process, nutrients are taken up by plankton and aquatic plants which then enter the food chain. When animals and plants die, their tissues are decomposed, and the nutrients can re-enter the community. If a system has a fewer nutrients within it, it is often referred to as oligotrophic. If a system has a higher amount of nutrients within it, it is often referred to as eutrophic.

Nutrient spiralling – how flow of nutrients and energy through ecosystems is cyclic, but open-ended. Natural systems are generally classified as *open* (there is some external input or output of nutrients) or *closed* (the system is self-contained). Generally, streams and rivers represent *open-systems* where energy, nutrients, and sediments unidirectionally. The nutrients will move back and forth among the water column, the bodies of both terrestrial and aquatic organisms, and the soil in the stream/river corridor while the water moves downstream. Nutrient *spiralling* involves movement downstream and the exchanges between the aquatic and terrestrial environments.

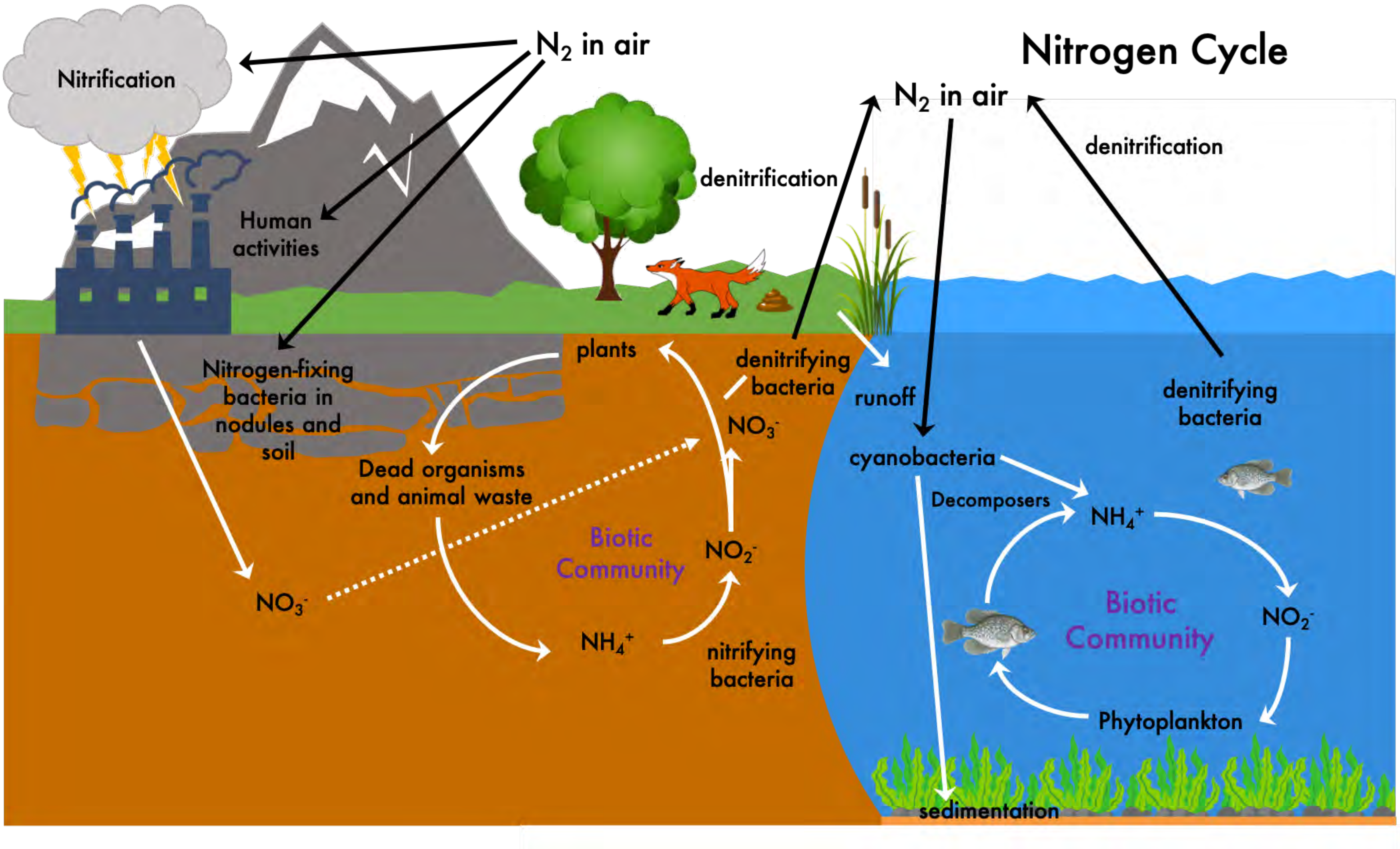
Carbon and energy cycling – Carbon and subsequent synthesized energy cycles through trophic levels (food-web). This transfer of energy is inefficient, with less than 1% of solar radiation reaching a plant used by consumers. Only 10% of energy will then be typically converted through trophic levels by consumers.

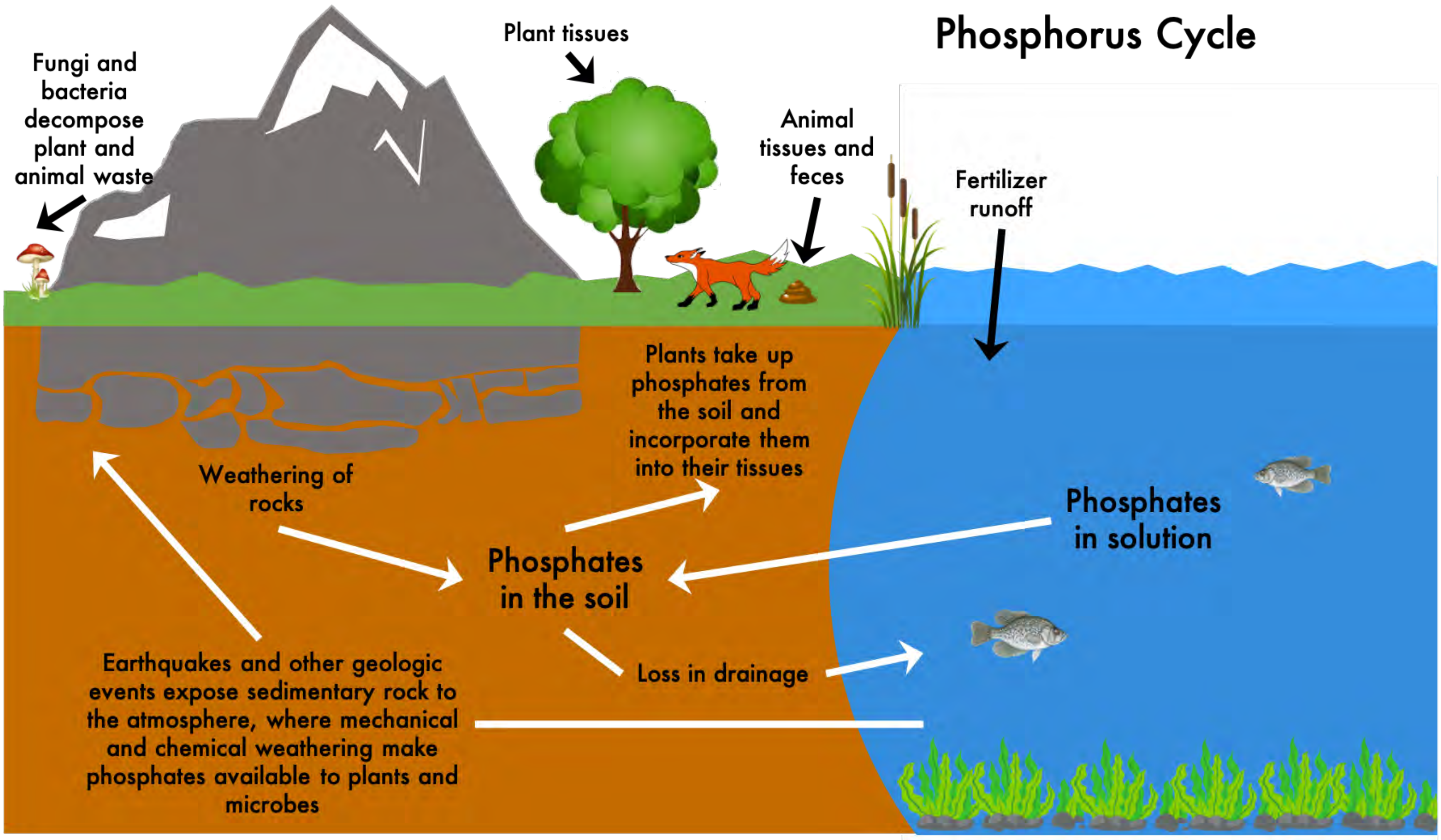


Nitrogen - Nitrogen is abundant throughout nature. It is often considered a 'nutrient' as it is *essential* for plant growth. Cyanobacteria is the only organism which can use nitrogen (N_2) directly from the air. Plants cannot use nitrogen in its pure state, rather plants uptake nitrates (NO_x) or ammonia (NH_3). Ammonia can be oxidised by other bacteria into nitrites (NO_2) and nitrates (NO_3). Nitrates (NO_3) are taken up by plankton and aquatic plants to grow. Animals further along in the food web obtain nitrogen by consuming other species. Animal excrement can also be rich in ammonia, and when animal excrements can enter into communities at varying levels. Fertilizers, sewage, and septic tanks can also be human-linked sources of nitrates.

Phosphorus - Phosphorus is another substance that is essential for life. Phosphorus often will combine with four oxygen atoms, forming a phosphate ion (PO_4). Algae and larger aquatic plants rapidly take up this ion for metabolic reactions and growth. Animals need phosphorus for similar reasons, but they uptake phosphorus through the food chain. Phosphate that is not combined in any molecules in plants or animals is called "orthophosphate", meaning "straight phosphate". Orthophosphate, the reactive form of phosphate, is the easiest to test for in the environment, compared to other phosphate forms. In most natural water bodies, orthophosphate is found in very low concentrations.

Therefore, phosphorus often acts as the ‘growth-limiting’ factor for producers (autotrophs), as plant growth and reproduction is limited by the amount available.





Decomposition - Decomposers, which include bacteria, fungi, and other microorganisms, are the other major group in the food web. They feed on the remains of all aquatic organisms and in so doing break down or decay organic matter, returning it to an inorganic state. Some of the decayed material is subsequently recycled as nutrients, such as phosphorus (in the form of phosphate, PO_4^{-3}) and nitrogen (in the form of ammonium, NH_4^+) which are readily available for new plant growth. Carbon is released largely as carbon dioxide that acts to lower the pH of bottom waters. In anoxic zones some carbon can be released as methane gas (CH_4). Methane gas causes the bubbles you may have observed in lake ice. The rate of decomposition is influenced by temperature, moisture, exposure, microbe community, vegetation available, etc. Temperature and moisture will impact the rate of metabolic activity involved in decomposition.

WATERSHED BOUNDARIES

Watershed Boundaries as they are defined by the National Hydrographic Network
© Natural Resources Canada, Government of Canada, 2019

A watershed is the area from which all water drains into the same body of water (river, lake, or ocean). The watershed boundaries indicate the extent of the drainage area. The perimeter of drainage areas are formed by the topography and other landscape characteristics.

The National hydrographic network (NHN) data is distributed by watershed, also known as NHN work units or the NHN index. Each NHN watershed boundary defines the drainage basin covered by a specific NHN dataset. Currently there are more than 1382 basins within the entire Canadian landmass. These watersheds form a continuous layer. The watersheds were created from the Water Survey of Canada Sub-Sub-drainage area and Fundamental drainage areas (FDA) of the Atlas of Canada. However, not that these watersheds evolve over time. They are updated when source data is updated or replaced.

WATERSHED CHANGE

Amazon River Flooding
© Michael Goulding

Change is ***constant***. It is a natural, vital feature of watersheds. Understanding how systems change over time and recognizing concerning changes are absolutely critical for effective integrated watershed management. Watershed change can be very complicated to describe and manage, especially as human and natural causes of change continue to interact in ways that have yet to be described or predicted.

CHARACTERIZING CHANGE

Changes are usually described in terms of **sources** or **causes** and the **effects** they bring about for the ecosystem, or watershed. The **frequency** of the change, or how often it occurs, as well as the **duration**, or how long the change occurs, will influence its effects on the watershed. Changes may also be characterized by the **intensity** or **magnitude** (degree or strength) of their impacts. The frequency and intensity of the change can strongly impact both plant and animal communities. Species that have evolved in highly dynamic ecosystems have adaptations that allow them to thrive or persist in these conditions. In watersheds, trees in lower flood plains that are subjected to frequent flood often have adapted to have roots that allow for oxygenation after being buried by sediment or water.

TYPES OF CHANGE

Watersheds experience change, over the seasons, years, and evolutionary time. There are wide variations in water flow through the systems, changing shorelines, channels, and corridors. Upland areas are going through changes due to ecological succession (as explained above), disease caused by pathogens, competition and predation, human activities, and many other factors. Even if a watershed was untouched by human development (as almost all now are), the biological and physical characteristics of the watershed do not remain constant over time. Systems go through dynamic changes that may have negative impacts on parts of the ecosystem while benefiting others with new opportunities.

Disturbance or **stress** are often used to describe change processes or events. *Stress* implies negative effects that change may have on an ecosystem. *Disturbance* is any change to the watersheds physical or biological characteristics. Natural disturbances can include:

- Fire
- Flood
- Severe storms
- Insects infestations
- Glacial movement
- Disease caused by pathogens
- Volcanic activity
- Earthquakes
- Hurricanes/typhoons
- Droughts
- Extreme temperatures (e.g., heat waves or cold snaps).

Anthropogenic disturbances (human caused) can include:

- Clearcutting
- Introduction of invasive species
- Major pollution events
- Climate change

Dynamic equilibrium, is often used to describe how ecosystems survive through and are modified by change.

NATURAL CHANGES

Flooding

Floods are natural events that influence stream ecology. For example, the **bankfull flood** stage (a flood level which fills the main channel and just begins to spill onto the floodplain), which is a flood level that recurs approximately every 1.5 years on average, is recognized as the primary force in determining the shape of the channel and the location of its floodplains. Animal and plant communities in rivers have spent millions of years adapting to the conditions around them, and floods have simply become a part of a larger cycle of stream ecology for them. Riparian corridors depend almost exclusively upon their streams' flooding cycles for their existence. During flooding, organic material is redistributed and living organisms often move downstream. Many fish wait until the first sign that the annual spring flood has begun to start **breeding**. Many insect larvae wait for flooding to begin to **lay eggs**, **hatch**, or **metamorphose**. Flooding provides a bonanza in new **food sources** for stream denizens. Floods flush insects, bugs, and worms from the land into the stream, which become food for fishes. Flooding results in increased **nutrients** for the stream. Nutrients (like nitrogen and phosphorus) are washed out of soil and animal feces. Nutrients added to the shallow, warmer waters of the floodplain lead to extra growth of **plankton**. The more nutrients present in a stream (up to a point), the more invertebrates will be able to live in it--and invertebrates form the base of the **food web**. Floods also wash dead brush and trees into the stream, providing **habitat** for countless animals. Flooding also creates opportunities for sediment and nutrients to be exchanged with floodplains. The amount and velocity of streamflow and the shape of the channel affect the size of materials transported and the stability of the stream bed, Intense flooding can lead to channel redistribution, new surfaces being exposed, new channels forming, riparian forests displaced, and major landslides. These floods can lead to a longer recovery period and more intense ecological recolonization.

Drought

The opposite of flooding, is the severe reduction in overall water volume or flow, due to droughts. These conditions can have major impacts on water chemistry by changing the relative contribution of groundwater compared to surface water. Changes in the contribution can then lead to changes in transparency, light conditions, thermal characteristics of waterbodies. Drought can also lead to the drying of temporary waterbodies, such as small streams, wetlands, and ephemeral pools often found in forests. Organisms, plants and animals, that are dependent on these waterbodies will disappear during periods of drought. The disappearance of these temporary waterbodies may also impact breeding or feeding behaviour of birds and amphibians who rely on these areas of water. Some species of fish, amphibians, and crustaceans are able to wait out periods of drought through periods of dormancy.

Droughts can also impact upland areas of watersheds. Extended periods of drought can lead to the death of more sensitive tree and shrub species and may impact the species composition of vegetation. These periods can also lead to the loss of topsoil that no longer is stabilized by vegetation or crops.

Fire

Fire frequency and intensity are controlled by ignition sources (e.g., lightening or human caused), fuel buildup (e.g., how much litter is present), and soil moisture. Fires are natural disturbances that help shape the plant and animal communities throughout the world. Some ecosystems, like grasslands and some forests, are subjected to fires over centuries and we consider them to be **fire-dependent**. These communities require fires to restore and maintain their ecological integrity.

Fires produce a mosaic of plant communities with different ages and species composition within a landscape. Fires burn with a variety of intensities depending on differences in terrain, wind, and other factors. Typically, areas where the fire has completely consumed the landscape, are scattered within patches of lightly burned and unburned areas. The fire increases the diversity of structure (arrangement of species) and species diversity over time.

Nutrients can also be released during a fire. The fire helps release nutrients bound in litter and woody debris on the ground. Fire will also reduce woody fuels to ash and consume the organic layer of soil. Nutrients are lost to the atmosphere as smoke, but many more nutrients are added to the soil. This "flush" of nutrients is available to plants that are re-establishing themselves in burnt areas.

The grasslands were created and maintained by the presence of frequent fires. Fires can remove encroaching trees and shrubs, as well as stimulating new growth of grass species, through the release of additional nitrogen and other nutrients. Ancient hunting peoples were also known to set regular fires to maintain and extend existing grasslands. Grassland plants, such as grasses, have long root portions that can survive the fires and sprout up again quickly. Some trees in these regions have thick bark to resist fire.

HUMAN-MODIFIED CHANGES TO WATERSHEDS

Anthropogenic changes to watersheds are widespread. Humans may change watersheds in new ways, such as clearcutting or the introduction of invasive species, but they may also alter the magnitude or frequency of natural change. If these changes, alone or together, exceed particular thresholds, recovery of ecosystems may no longer be possible.

Climate Change

Throughout its history, Earth's climate has varied, reflecting the complex interactions and dependencies of the solar, oceanic, terrestrial, atmospheric, and living components that make up planet Earth's systems. Human activities, such as burning fossil fuels and deforesting large areas of land, have had a profound influence on Earth's climate. The accelerated human-caused climate change we are experiencing today will have a profound impact on all parts of the earth's ecosystems.

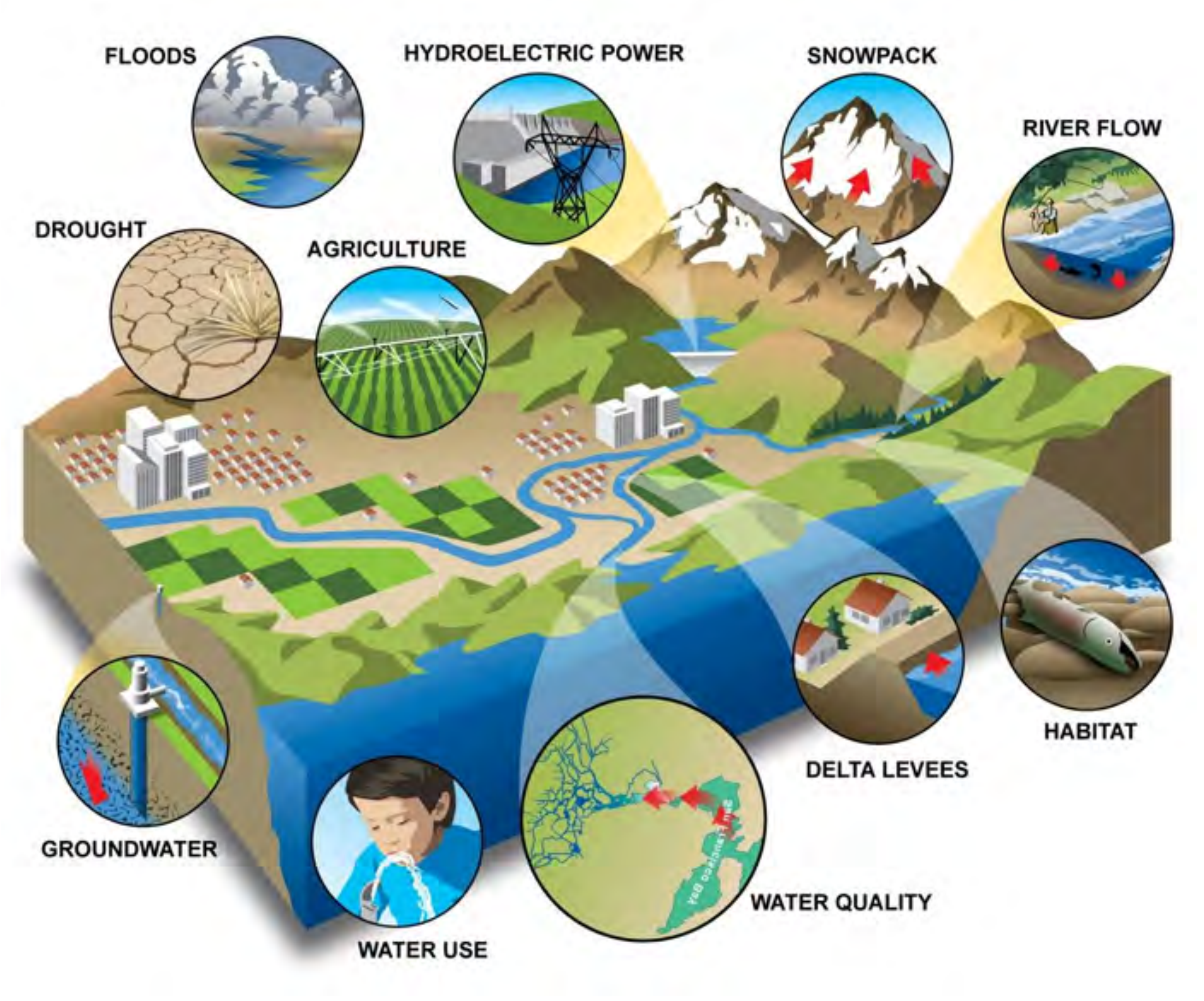
Water in its various forms (solid, liquid, vapour), is always on the move in the hydrologic cycle. Higher average global temperatures and more extreme, less predictable, weather conditions caused by climate change, are already having a measurable impact on this cycle, altering the amount, distribution, timing, and quality of available water. It is predicted these changes will also impact water quality. These changes will have wide-ranging consequences for human societies and ecosystems.

Observed warming over the last several decades have been linked to alterations in the hydrological cycle.

- Increased water vapour in the atmosphere
- Changing precipitation patterns, intensity, and extremes
- Reduced snow cover and melting of ice
- Changes in soil moisture and runoff

Other predictions include:

- Increased precipitation at higher latitudes and parts of the tropics and decreased in other areas
- Increased annual average river runoff and water availability in some areas (high latitudes and wet tropical areas) and decreased in others (mid-latitudes and dry tropics).
- Increased precipitation intensity and variability, leading to increased risk of flooding and drought in many areas
- Declines in glaciers and snow cover, reducing water storage
- Reduction in overall water quality due to higher water temperatures and changes in extreme weather (storms, flooding, etc.)
- Changes in food availability, stability and access due to changes in water quality
- Function and operation of existing water infrastructure (hydropower, flood defences, drainage and irrigation systems) and water management practices will be negatively impacted



Impacts of climate change on watersheds
© US EPA, 2009

Climate change adaptation options need to be designed to ensure safety and health of water supply during normal and drought conditions. **Mitigation** measures should be put in place to reduce the impacts of climate change on water resources. Finally, many gaps in knowledge exist on the consequences of climate change on our aquatic ecosystems. Further **research** needs to be conducted so that we can properly prepare and understand these changes.

Water Scarcity

Water scarcity may be the most underrated resource issue the world is facing today. Currently, 70% of world fresh water use is for irrigation and between 1950 and 2000, the world's irrigated area tripled to roughly 700 million acres. Today, more than 18 countries, containing half the world's people, are over pumping their aquifers, or sources of fresh water. Among these are the big three grain producers—China, India, and USA.

Yemen is facing a severe water crisis with some estimates suggesting the capital, Sanaa, could run dry in 10 years. With little being done to harness rainfall in the country, farmers are drilling deeper than ever for water - without any government regulation. Agriculture uses around 90% of the country's water resources - with around half of that being used to cultivate the herbal stimulant khat. At this moment, it is estimated that half of Yemen's population has no access to clean water.

Climate change is also hydrological change. Higher average global temperatures and more extreme, less predictable, weather conditions caused by climate change, are already having a measurable impact on this cycle, altering the amount, distribution, timing, and quality of available water. It is predicted these changes will also impact water quality. These changes will have wide-ranging consequences for human societies and ecosystems.

Modification of Flow

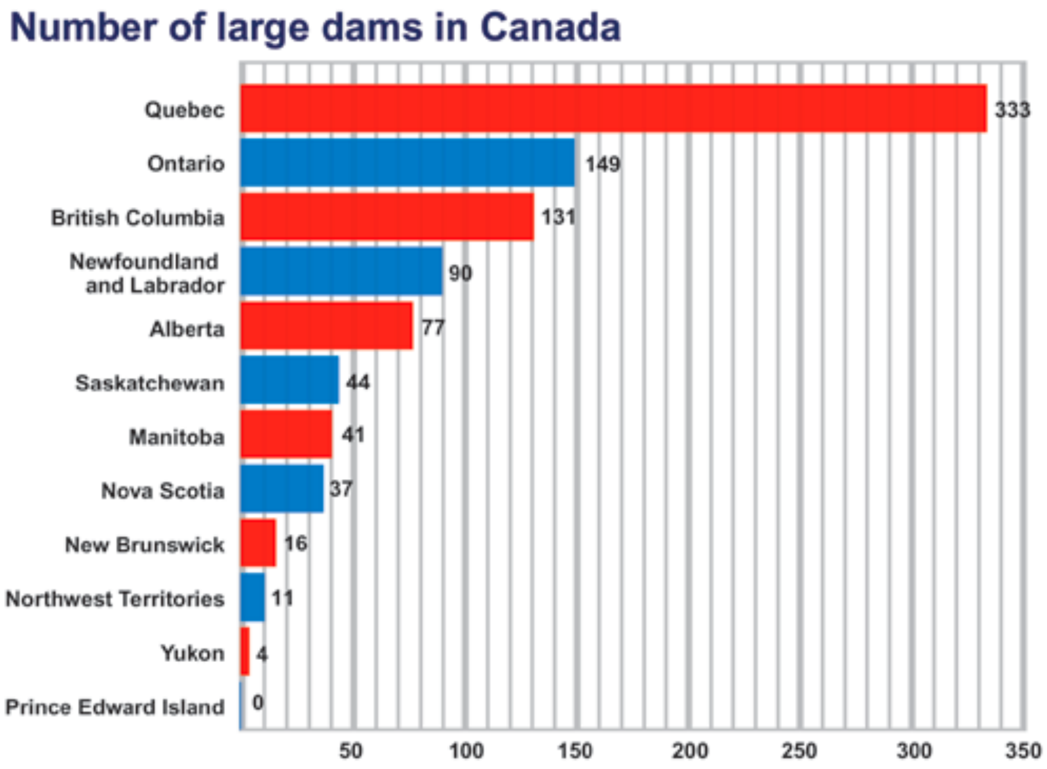
Anthropogenic developments, like agriculture, urbanization, and timber harvest alter watershed runoff and flow in significant direct and indirect ways. One such modification, is how river flow is impounded (stopped) or diverted. Often these two modifications occur together, resulting in flow amplitude reduction, base flow variation, differences in temperature regimes, and the movement of materials and nutrients is reduced. Diverting water permanently (e.g., a diversion channel) or temporarily (e.g., when fixing a bridge) can significantly affect the natural character of a waterway and the surrounding habitat.

The overall connectivity between the reaches of the river and between the river and its floodplain are changed. Ultimately it has negative impacts on biodiversity and ecological processes.

Water can be diverted using **instream barriers** such as dams, weirs, culverts, canals, and pipes. **Dams** hold back flows of surface or underground streams for controlled release (to provide maximum power generation or to control the destructive power of storm water). Canada ranks as one of the world's top ten dam builders. **Reservoirs** (large flooded areas upstream) created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability.

Dams and their resulting reservoirs impact the water quality and biotic community of a stream system. The land upstream of the dam is flooded, which may mean the loss of valuable wildlife habitat, farmland, forests, or town sites. Accumulation of sediments in the reservoir can have a negative impact on water quality (turbidity), and decomposition of flooded vegetation can lead to the release of huge amounts of greenhouse gases (methane, carbon dioxide) and mercury. Fish in reservoirs are often highly contaminated with mercury due to the enhanced availability of mercury in the ecosystem. Eutrophication may also occur at a faster rate and adversely affect water quality.

Diversions redirect water flow to an alternate location (e.g., changing the pathway of a river, or draining a portion of a lake), and are frequently used in mining and other industrial activities. Historically, diverting flow from one basin to another has been done for energy generation, irrigation, and industrial output. Inter-basin (between watersheds) diversions can have undesirable social and environmental consequences. For example, the amount of water removed in relation to the amount of water available, existing water demand and uses, quality of water transferred, and potential for introduction of invasive species and pathogens, can all have significant impacts. Major diversions and transfers have been used to fulfill water resource and economic development objectives, but it is widely recognized that we



The number of large dams in Canada by province

© Environment Canada

have moved away from the era of large-scale diversions and transfers in North America because of environmental and social considerations.

Agricultural Use

Water is withdrawn mainly for irrigation (86.4%) and livestock watering (9.8%). Irrigation is needed mainly in the drier parts of Canada, such as the southern regions of Alberta, British Columbia, Saskatchewan, and Manitoba. Irrigation is also used in Ontario and the Maritimes for frost control. Since so much of the water used in irrigation evaporates, only a small fraction is returned to its source. **Irrigation is a highly consumptive use.** Canadian agricultural producers used just over 2 billion cubic metres of water for irrigation in 2016, about 22% higher than in 2014.

Mining

This category includes metal mining, non-metal mining, and the extraction of coal. Water is used by the mining industry to separate ore from rock, to cool drills, to wash ore during production, and to carry away unwanted material. Mining recirculates its water to a greater extent than any other sector, so although the mining industry had a gross use equal to about half of that used in agriculture, mining accounted for only 1% of all water intake in 2005 (compared to 9% in the agricultural sector). Mining activities have great potential to **contaminate** water with harmful pollutants, so even if the water is technically returned to its source, it may not be fit to support aquatic organisms.

Urbanization

Urban development has and continues to have some of the most significant impacts on watersheds. As watershed vegetation is replaced with impervious surfaces, like paved roads and parking lots, how water moves through a system is modified, increasing surface run off and earlier and higher peak flows following storms. The frequency of flooding is also increased. Often the problems are compounded by channelization of small streams and the use of storm sewers.

Urbanization also leads to increased contaminant inputs from anthropogenic sources. Contaminants may enter directly into streams and lakes from **point-source** (e.g., sewage treatment plants) and **non-point source** (e.g., agricultural runoff). They can also lead to increasing additions of limiting nutrients (especially phosphorus) into a watershed. For example, in the 1970s phosphate was banned as an ingredient in detergents (laundry, dish soap, personal hygiene products, etc.) to reduce eutrophication of lakes (at the time it was in response to the eutrophication of Lake Erie).

Introduction of Exotic Species

An invasive species is an exotic (originating from another region of the world) species whose introduction causes or is likely to cause economic harm, environmental harm, and/or harm to native species (including human) health. Species include plants, seeds, eggs, spores, other propagules, and animals (e.g., mammals, reptiles, amphibians, fish, insects and other invertebrates). Often human actions have permitted the species to cross a natural or artificial barrier to dispersal (e.g., mountains, oceans, highways, urban development, etc.). **Although all invasive species are non-native, not all non- native species are invasive**. Non-native species are only considered invasive if they have harmful ecological, environmental, or economic affects. All ecosystems are at risk from the harmful effects of invasive species. The adverse effects of invasive species vary widely, from the extirpation or extinction of native species to long-term effects on ecosystem function.

Invasive species can threaten an area's biodiversity by overwhelming native species, damaging habitat, disrupting food sources, and introducing parasites and disease. Most invasive species have little to no population control mechanisms in place and often increase in numbers rapidly. Once invasive species are established they can be difficult, or impossible, to control and remove. **Invasive species are often also referred to as aliens, exotics, non-native, or nonindigenous species**.

Invasive species tend to crowd out and replace native species. They can severely damage ecosystem health and harm human activities, such as agriculture, forestry, fisheries, and recreation.

Economic

Invasive species can have large impacts on the economy, both positive and negative. Government and private landowners may incur significant cost to repair damage done by invasive species. Funds are also spent on monitoring and educational programs.

Social

Invasive species can have negative effects on societies. Invasive species can bring novel pathogens with them, leading to the introduction of disease, they have the potential to increase human health impacts including allergies and irritations, and may reduce recreational and tourism opportunities.

Environmental

Invasive species are a major threat to our environment because they can:

- Threaten biodiversity
- Introduce pathogens
- Increase predation and competition
- Hybridization
- Change community structure
- Change habitats, fire regimes, and alter ecosystem function and services

Biodiversity and community structure

Invasive species are the second most important threat to global biodiversity, next to climate change. It has been estimated that almost half of the species in North America that are at risk of extinction are endangered because of the effects of invasive species. Invasive species can spread pathogens (causing disease), act as new predators, parasites, or competitors, alter habitat, and/or hybridize with local species.

Pathogens and Parasites

Invasive species often bring novel parasites with them (i.e., additional invasive species) when they move into a region. The introduction of new parasite species to a region can have many of the same effects as free-living invasive species. Their presence may enhance, inhibit, or have no effect on the invasion of a free-living species.

Predation and Competition

Invasive species that are predators can severely reduce the population sizes of native species, sometimes even to **extirpation** (extinction from an area) or **extinction** (no individuals left). Native prey species have not evolved defenses against these new predators. Zebra mussels (*Dreissena polymorpha*) were accidentally brought to North America from Russia in the ballast of ships. Zebra mussels change aquatic habitats by filtering large amounts of water and reducing densities of planktonic organisms.

Hybridization

Hybridization occurs when two different species mate with each other and produce viable offspring. If the invasive species is more abundant than the native species, this hybridization may lead to a slow disappearance of the native species genes, and eventually lead to the extinction of the native species.

Alter habitat and ecosystem functions

Invasive species, particularly plant invaders, can alter the fire regime, nutrient cycling, hydrology, and energy in native ecosystems. They can greatly diminish the abundance or survival of native species and even block navigation or enhance flooding.

HOW CHANGE IMPACTS WATERSHED PROCESSES

Changes to watersheds are often caused by a combination of factors, leading to more complex issues than one change alone. Problematic change often results from interactions from both natural and human-induced disturbances. Even if the individual stressors are low to minimal impact, ecological processes and relationships may be strongly impacted by the **cumulative impact** of multiple stressors acting on a system together. Further, one change may end up leading to more changes, almost like dominos.

Interactive effects may also lead to significant change within a watershed. When two or more changes act together to produce a more severe or different impact than the stressors alone, this is known as an *interactive effect*. For example, climate change often increase the number of disturbances (e.g., fire frequency), which then may alter plant and animal community composition.

Change can also reach **threshold levels**. If a change goes beyond a specific threshold level, it also results in a state in which previous relationships are no longer viable and new influences dictate the state and structure of ecological communities. For instance, microbe activity increases with temperature until a specific point, or threshold, where they move beyond their thermal limit, and most die.

INTEGRATED WATERSHED ANALYSIS AND PLANNING

Integrated watershed management (IWM) is the process of **managing** human activities and natural resources based on a watershed approach. This method allows us to protect important water resources, while also addressing important issues such as the current and future impacts of rapid human development and climate change.

PRINCIPLES OF INTEGRATED WATERSHED MANAGEMENT

1. *Geographical Scale* - The boundaries of the watershed should be used as the planning boundaries in an integrative approach. The plan should consider appropriate scales when making management plans and integrate the connectedness to upstream and downstream watershed.

2. *Ecosystem Approach* - The IWM should consider the best scientific knowledge available, consider cumulative impacts, and promote watershed approaches.

3. *Adaptive Management* - The plan should include flexible and continuous improvements and adaptations as knowledge improves. The policies and management should incorporate innovative designs, practices, and technology.

4. *Integrated Approach* - The IWM plan should include land, water, and infrastructure planning, investment. It should consider the direct, indirect, or potential impacts of all actions and interdependencies between subjects (e.g., how changes to the land impact the water and vice versa).

5. *Cumulative Impacts* - The cumulative effects of the IWM planning on the environment and the interactions of the entire ecosystem should be considered.

6. *Precautionary Principle and No Regrets Actions* - If there is uncertainty about how an action may impact the surrounding environment, great caution should be exercised.

7. *Proactive Approach* - Planning should attempt to prevent environmental degradation. It is much more cost-effective and better for the environment to prevent degradation then it is to repair it.

8. *Shared Responsibility* - Responsibility for the program and policy development should be shared by all interested participants.

9. *Engaging Communities and Indigenous Communities* - Integrated watershed management processes and policies should recognize and support the identity, culture, and interests of local communities and indigenous communities. Process should include meaningful participation by both groups, as they serve a vital role in IWM because of their knowledge and traditional practices.

10. *Sustainable Development* - the IWM plan should include development that meets both economic and social needs while also not compromising the environment for current and future generations.

All watershed management plans are unique and should reflect the landscape and the concerns of the community within each watershed.

Benefits of integrated approach

Integrated watershed programs, coordinated on a watershed basis, is good for environmental, financial, social, and administrative reasons. For example, by reviewing the results of assessment efforts for drinking water protection, pollution control, fish and wildlife habitat protection and other aquatic resource protection programs at the same time, managers from all levels of government and local communities can better understand the cumulative impacts of various human activities and determine the most critical problems within each watershed. Using this information to set management priorities allows public and private managers to allocate the limited financial and human resources to address the most critical needs. Establishing environmental indicators helps guide activities toward solving those high priority problems and measuring success in making real world improvements.

The IWM approach can also result in cost savings by leveraging and building upon the financial resources and the willingness of the people with interests in the watershed to take action. Improved communication and coordination can reduce expensive duplication of efforts and conflicting actions by different parties. The watershed approach can help enhance local and regional economic viability using environmentally sound methods and procedures consistent with watershed objectives. Finally, the IWM approach strengthens teamwork between the public and private sectors at the federal, provincial, indigenous community, and local levels to achieve the greatest environmental improvements with the resources available.

MANAGEMENT PRACTICES

Management practices should include three main pillars:

1. Improve water resource management through the implementation of relevant and effective integrated management tools and techniques.
2. Strengthen the principles of governance, planning, adaptive management, and capacity building in local, regional, and transboundary water resource regimes.
3. Provide participants with the ability to develop skills and knowledge needed for addressing the urgent needs in the water resource sectors.

APPROACHES ACROSS CANADA

From Summary of Integrated Watershed Management Approaches Across Canada, Canadian Council of Ministers of the Environment, 2016

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern.

Integrated Watershed Management (IWM) is a continuous adaptive process of managing human activities and ecosystems at the watershed scale that integrates multiple concepts and methods, including water and land use planning and management (e.g., protected areas, source water protection, etc.), and evaluates and manages cumulative effects from multiple environmental stressors. IWM is intended to bring together many aspects of governance such as policy, planning and legislation on the basis of a geographic area (a watershed) and it also brings together people and their activities to build relationships among actors.

This summary report contains CCME's IWM definition and principles and describes Canadian jurisdictions' IWM concepts and approaches. It is designed to enhance the capacity of jurisdictions to apply integrated watershed management principles and to develop policies and programs consistent with the principles. Research support for this report was provided by Marbek Resource Consultants Ltd. In conducting this research a literature review was undertaken using primarily internet sources for publicly available government documents. Research also included telephone interviews and e-mail correspondence with representatives from Canada's 14 federal, provincial and territorial governments.

Strategic Vision for Water

In recognition of the importance of water to Canadians, CCME endorsed a Strategic Vision for Water. The first goal in the vision is for the protection of aquatic ecosystems on a sustainable watershed basis.

Vision: Canadians have access to clean, safe and sufficient water to meet their needs in ways that also maintain the integrity of ecosystems.

Mission: CCME facilitates forward-thinking research and integrated policy, standard and/or guideline development, that contribute to the sustainable management, protection, restoration and conservation of Canada's water.

Goals:

1. Aquatic ecosystems are protected on a sustainable watershed basis.
2. Conservation and wise use of water is promoted.
3. Water quality and water quantity management is improved, benefiting human and ecosystem health.
4. Climate change impacts are reduced through adaptive strategies.
5. Knowledge about Canada's water is developed and shared.

While few Canadian jurisdictions have established clear mandates or departments to undertake IWM, many Canadian jurisdictions have informal IWM planning approaches and are working to continuously improve the plans developed. Some jurisdictions have scoped their approaches to target specific aspects of IWM, such as drinking water source protection.

Jurisdictions use a wide variety of governance approaches to IWM including grassroots, jurisdictional authority and combination approaches. Jurisdictions with IWM mandates commit a range of funding resources, staff expertise and guidance tools to work towards watershed plans including public engagement. Taking time for consultation, beginning early in the planning process, and continuing throughout the planning and implementation phases is highly recommended by jurisdictions and cited as a key factor in successful IWM framework development and implementation.

In the context of developed nations such as Canada, other more specific major factors that have influenced and continue to influence the development of IWM include:

- Recognition that environmental issues such as water are multi-scale. Individual activities in one area often have impacts that are felt in another area (e.g., jurisdiction, watershed, or downstream/upstream in the same watershed), and could additively and cumulatively have significant regional, Canada-wide, international or global impacts. Thus, jurisdictions within and between countries need to collaborate in identifying, avoiding, minimizing and mitigating these large-scale and often significant negative impacts.

- Recognition by federal, provincial and territorial governments, that it is neither desirable nor feasible to have a single "water agency" lead all water and land-related resource management. Thus, there is a need to bring together (or integrate) the efforts of several government agencies within and, where appropriate, between jurisdictions.

- Consideration of how water is connected through the hydrologic cycle, and groundwater and surface water must be connected in our management activities. This type of thinking also suggests that we should connect water resources, and the associated impacts on these resources from activities on land, to the ecosystems and to human health which rely on secure and safe water. Climate change reminds us that the water resources (water, ice and snow) and distributions of precipitation must not be taken for granted.

- Recognition of water shortages, flooding and water quality issues throughout the globe, including Canada (e.g., southern Saskatchewan, Red River, Saguenay River, Richelieu River, Walkerton, the Great Lakes and others).

- Consideration that increased water users and types of water use, including increased awareness of the need to better balance ecosystem needs and withdrawals, has led to more conflicts and more difficulty in achieving effective conflict resolution. IWM is seen as a way to better manage and resolve water use conflicts among various sectors (e.g., recreation, industries, agriculture, municipalities, energy production, etc.).

- Recognition of the need for participatory or community-based management approaches that could eliminate or reduce user conflicts, and provide a basis for better implementation. These approaches also serve as a way to ensure problems are well scoped and alternative solutions well considered.

- Awareness that funding for water resources management is limited and requires creative approaches to distribute the costs of planning, implementation and monitoring among the many participants including those who use and benefit from water.

- Awareness that climate change will alter what we have come to expect from "normal" climate conditions. Current thinking on IWM best practices recognizes the high level of uncertainty associated with our ability to predict the future, and that we must be prepared for increased variability and change. Thus, adaptive approaches that rely on data collection, analysis and experimentation are a more recent aspect of IWM.

- Appreciation that Aboriginal people, living in parts of many watersheds throughout Canada, rely on many water resource services, and should be involved in the planning and management of those resources. Increased awareness of the relatively poor drinking water quality in many Aboriginal communities has led to a desire to redress this significant problem.

Since 1992, these factors have influenced the development and practice of many IWM initiatives in Canada.

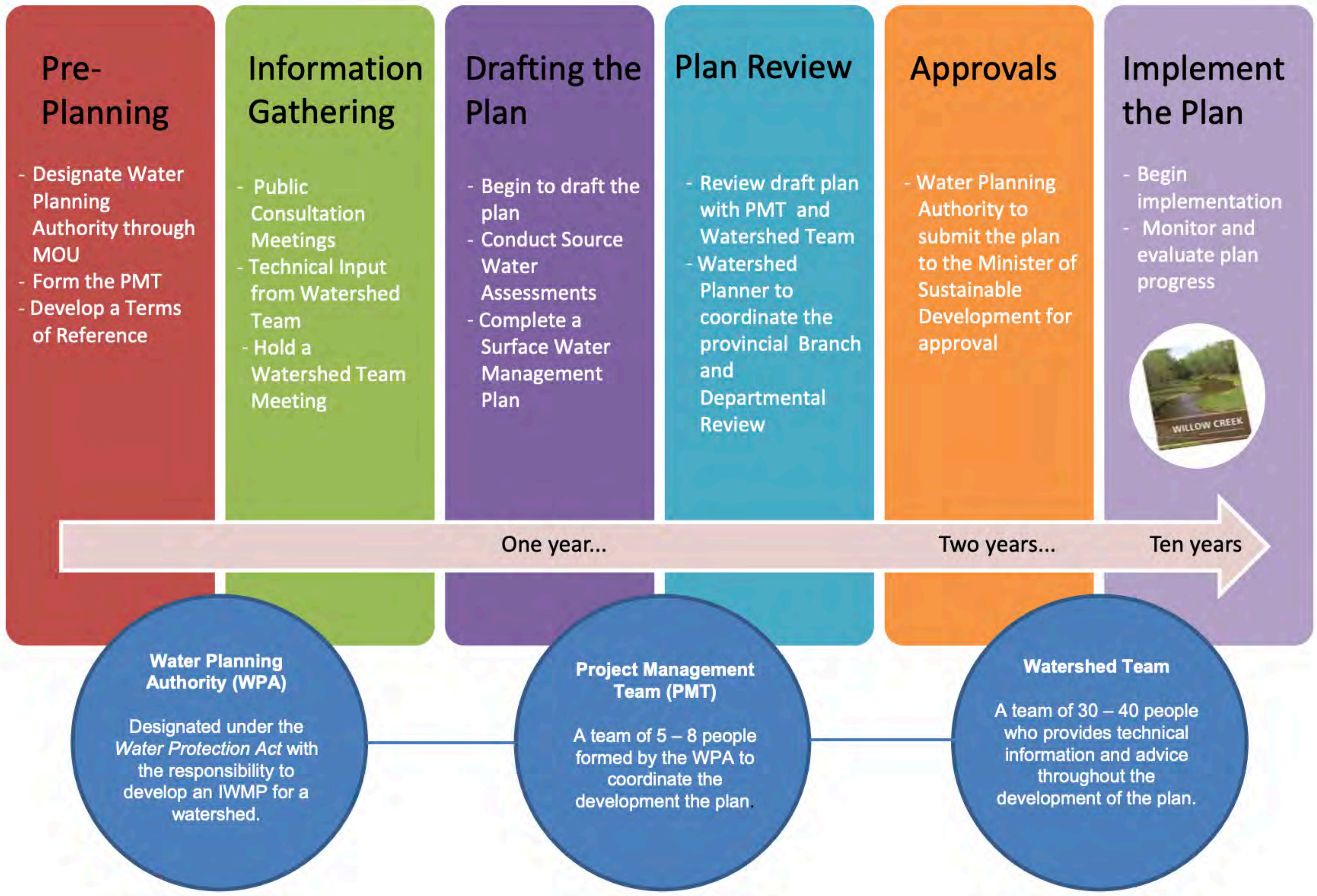
Watersheds in Canada - The Challenge of Scale

Canada is a very big country with very big watersheds (e.g., Great Lakes – St. Lawrence Basin); it is also a country of very small watersheds (e.g., those found on Prince Edward Island). How IWM is implemented across scale creates an interesting challenge for resource managers. The appropriate scale for IWM depends on the objectives, resources, capacity, leadership and jurisdiction of proponents for IWM. The objectives for IWM are related to existing conditions as well as desired future conditions in the watershed, stressors and drivers, socio-economic factors and other considerations unique to a region or jurisdiction. Each watershed is nested within a larger watershed, from the drainage area for a small headwater stream to continental scale basins.

MANITOBA WATERSHED DISTRICTS PROGRAM

In Manitoba, ***Watershed Districts***, play a large role in plan development and implementation. Manitoba watershed districts program, previously known as conservation districts, are a land and water conservation partnership. The *Watershed Districts Act* (2020) transitioned 18 conservation districts into 14 new watershed districts whose boundaries were based on existing watersheds. The watershed districts program is administered and managed by the watershed planning and programs section. This group coordinates and supports IWM planning. Watershed districts are also a partnership between the province and local municipalities to protect, restore, and manage land and water resources on a watershed basis. Each district is charged with developing and implementing programming to improve watershed health, while four districts also have a surface water infrastructure mandate to maintain provincial waterways within their boundary.

Watershed districts can also be designated as a Water Planning Authority for integrated watershed management planning under *The Water Protection Act* in Manitoba. They provide leadership with the development and implementation of watershed plans, as described in



Pre-Planning
- Designate Water Planning Authority through MOU
- Form the PMT
- Develop a Terms of Reference

Information Gathering
- Public Consultation Meetings
- Technical Input from Watershed Team
- Hold a Watershed Team Meeting

Drafting the Plan
- Begin to draft the plan
- Conduct Source Water Assessments
- Complete a Surface Water Management Plan

Plan Review
- Review draft plan with PMT and Watershed Team
- Watershed Planner to coordinate the provincial Branch and Departmental Review

Approvals
- Water Planning Authority to submit the plan to the Minister of Sustainable Development for approval

Implement the Plan
- Begin implementation
- Monitor and evaluate plan progress

One year... Two years... Ten years

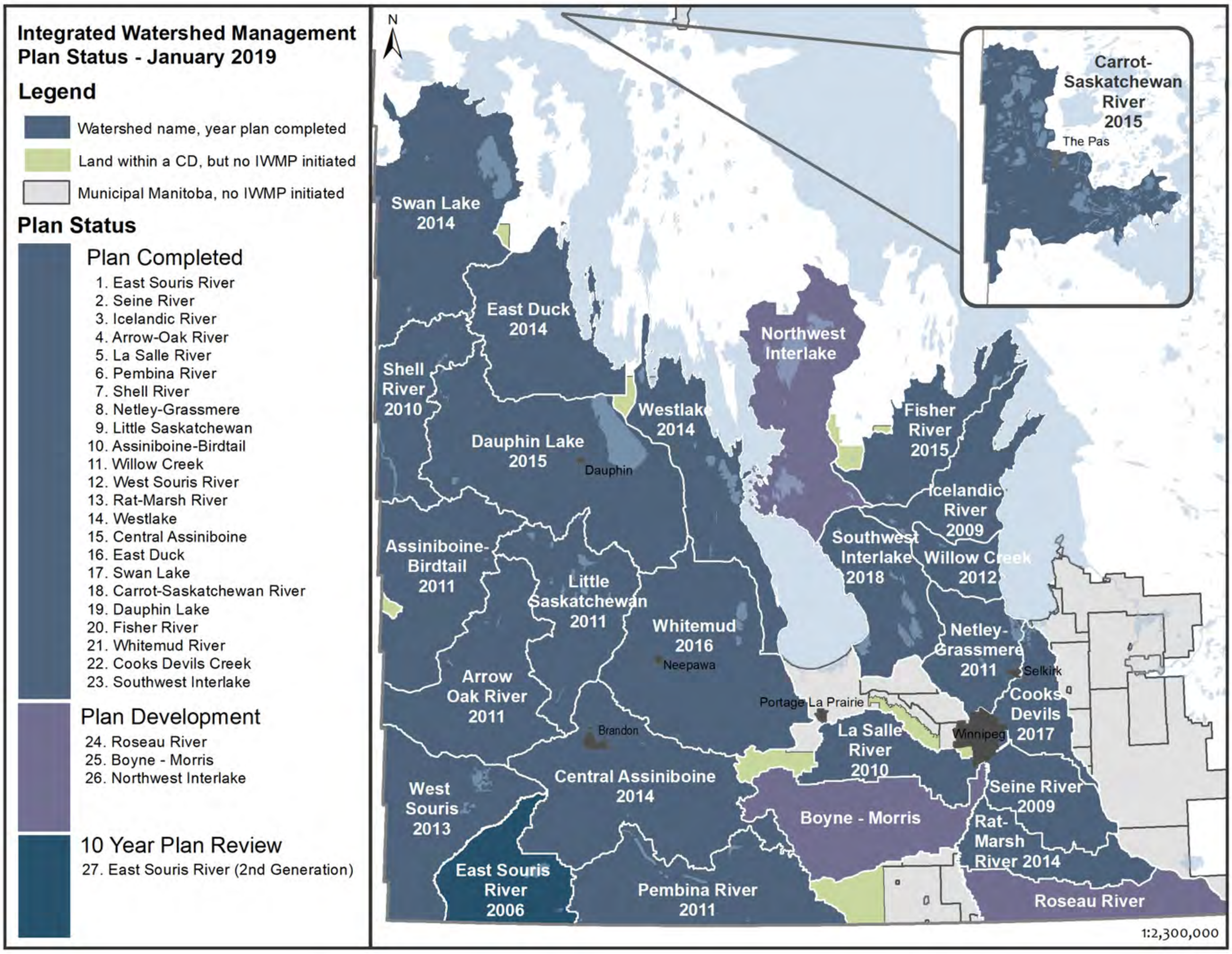
Water Planning Authority (WPA)
Designated under the *Water Protection Act* with the responsibility to develop an IWMP for a watershed.

Project Management Team (PMT)
A team of 5 – 8 people formed by the WPA to coordinate the development the plan.

Watershed Team
A team of 30 – 40 people who provides technical information and advice throughout the development of the plan.

Integrated Watershed Management Planning in Manitoba
© Government of Manitoba

the figure below. A watershed plan assists a district in planning long-term and short-term goals and identifying priority project to improve watershed health. Currently there are 26 IWM plans in various stages of completion and one plan under renewal in Manitoba (as of 2020), within the 18 districts.



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