Guide to the Science of Climate Change in the 21st Century

Chapter 6
Hydrological Cycle

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Table of Contents

List of Figures

6.0 Hydrological Cycle

6.1 Introduction

The hydrological cycle describes how water, H_2O, is stored and transported from surface water storage to the atmosphere, returns to the surface and subsurface of the Earth where it might remain in temporary storage and ultimately returns to the atmosphere and back to surface water storage.

6.2 Basic elements of the hydrological cycle

Figure 6.1 illustrates the various elements and processes in the hydrological cycle.
Water leaves the ocean and other water bodies (liquid form) to the atmosphere (vapour form) by a process known as evaporation. Water will also enter the atmosphere as a result of plant transpiration and direct evaporation from the soil by a process known as evapotranspiration which lumps both plant transpiration and evaporation from the soil together since it is very difficult to separate the two processes over land surfaces. Evaporation and evapotranspiration require energy to turn the liquid water into vapour. This energy now exists in the water vapour and is known as the latent heat of evaporation. So, evaporation and evapotranspiration actually transfer energy from the Earth into the atmosphere. Water will also move directly into the atmosphere from frozen bodies of water through a process known as sublimation. The water vapour in this case carries the energy required to melt the ice and the energy required to turn the liquid into vapour. Atmospheric circulation will carry the moisture laden air to where it will leave the atmosphere in a process called precipitation after it becomes liquid or ice and ultimately return to the ocean.

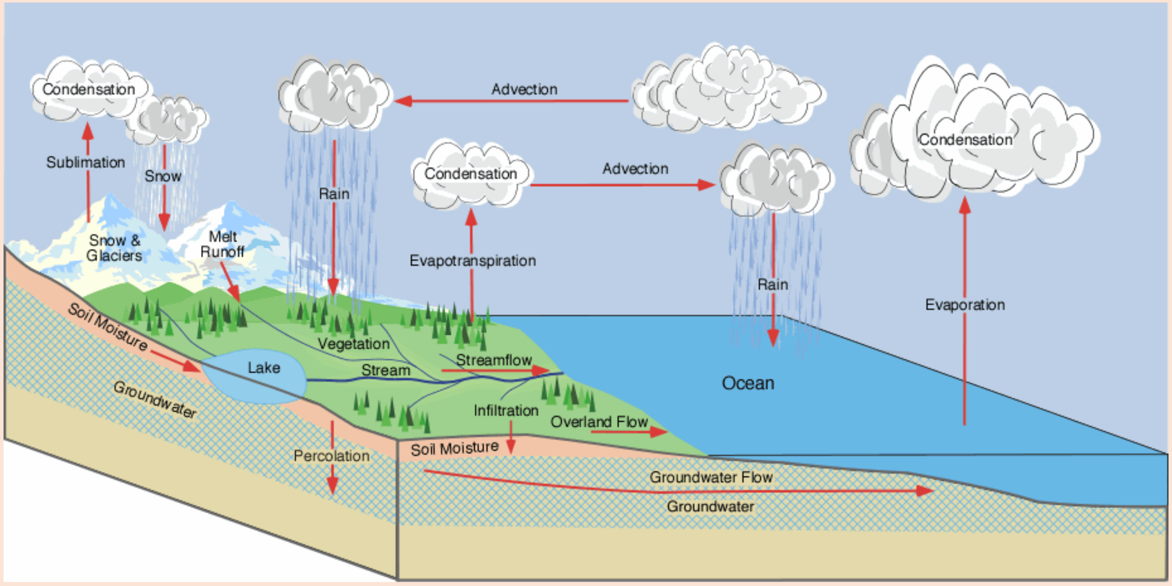

Figure 6.1 Hydrological cycle. http://www.physicalgeography.net/fundamentals/5c_1.html

6.3 Evaporation and evapotranspiration

The rate at which water will move into the atmosphere will depend on the temperature of water source (surface of the ocean and other water bodies and the land and biomass), the amount of energy being received by the contributing water sources, the temperature of the air and the amount of water already in the air above the contributing water sources. Winds can enhance the evaporation and evapotranspiration processes by physically transporting air with high concentration of water vapour away from the contributing sources allowing air with low concentration of water to move next to contributing sources (advection and convection).

6.4 Convection and cloud formation

Convection processes will carry the air containing the moisture vertically until it has a similar density to the surrounding atmosphere. Moisture laden air may be forced upwards by mountains (orographic effect) or when moving warm air is forced to rise when it collides with cold air.

Water vapour will cool as it is carried upwards and it will eventually condense to form liquid or solid water particles around nuclei such as dust, ash or smoke particles so releasing the energy it needed to change it into a vapour form in the first place (latent heat). The particles are seen as clouds. The latent heat added to the air warms it and it continues to rise upward if possible. This process can result in very large convective storms that reach the troposphere.

Water is a very effective absorber of heat energy (infrared radiation). In this sense water vapour is considered a greenhouse gas. Infrared radiation from the Sun and from the Earth surface will be absorbed and warm the atmosphere and this heat energy will be radiated in all directions – outer space and back to the Earth's surface.

Clouds formed as part of the hydrological cycle will reflect incoming solar radiation (short wave) back into space. A satellite image of Earth shown in Figure 6.2 shows the extent of reflecting cloud and ice cover. The manner with which clouds can affect global temperature is explained in a guest brief in the newsletter, 'Carbon Brief', https://www.carbonbrief.org/guest-post-why-clouds-hold-key-better-climate-models.

Research reporting cloud formation and their affect on the energy budget is reported in the journal 'Nature Climate Change' , https://www.nature.com/articles/s41558-021-01038-1 and summarized by one of the authors in 'Carbon Brief', https://www.carbonbrief.org/cooling-effect-of-clouds-underestimated-by-climate-models-says-new-study?utm_campaign=Feed%3A%20carbonbrief%20%28The%20Carbon%20Brief%29&utm_content=20210604&utm_medium=feed&utm_source=feedburner . The authors discuss the formation of clouds and production of rainfall stressing that climate models have underestimated the cooling effect from clouds.

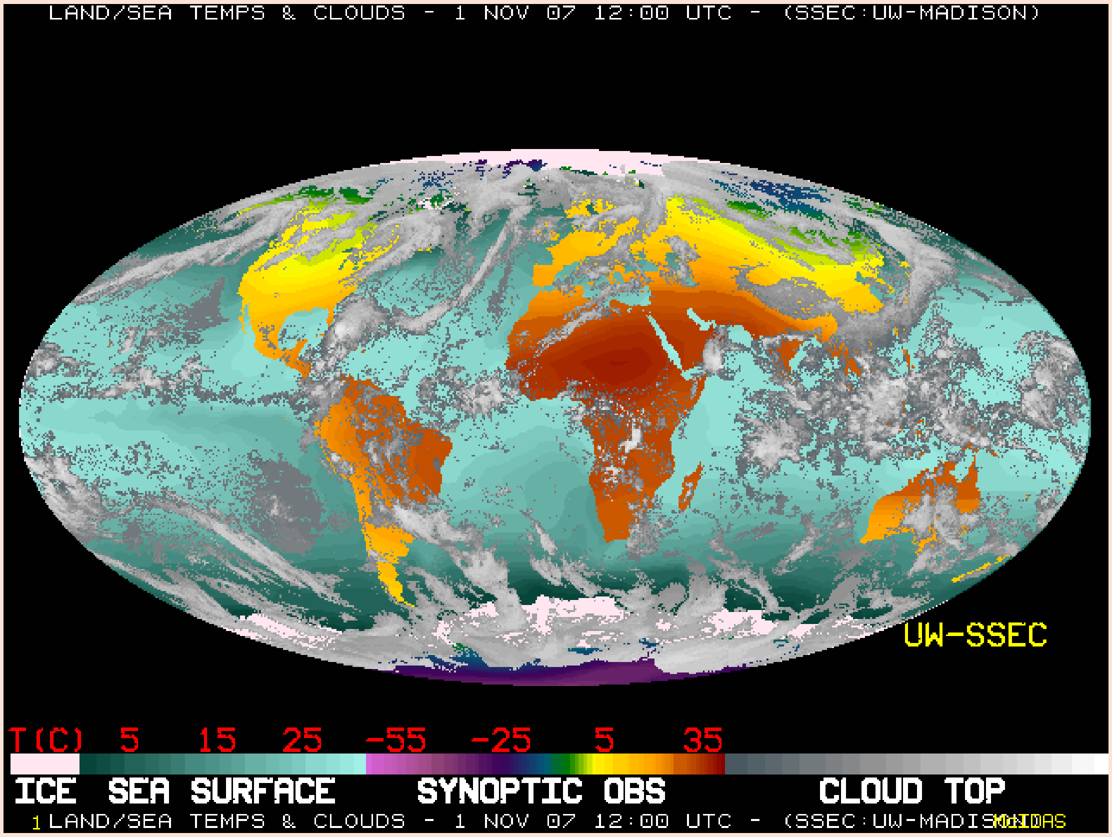

Figure 6.2 A satellite image of Earth showing the extent of reflecting cloud and ice cover.

6.5 Precipitation

Liquid or ice particles that form in the atmosphere will grow in size to the point where they fall to the Earth surface (precipitate) as rain or snow (there are several other types of precipitation but they are minor in comparison to rain or snow). While in the atmosphere the moisture laden air and clouds are being transported by both the horizontal and vertical movement of air (atmospheric circulation) and the precipitation process may occur a very long distance from where the moisture originally entered the atmosphere.

Water that is evaporated must also be precipitated. 'What goes up must come down.'

6.7 Runoff

All precipitation will eventually return to the ocean. If it occurs over land surfaces it may drain over the surface (overland flow) or infiltrate into the soil and percolate into the groundwater where it will then drain into nearby surface water (rivers and lakes) or directly into the oceans (groundwater flow). Snow may be stored for short periods of time, melt and then drain (seasonal accumulations); or, portions may accumulate to form ice sheets, ice caps or ice fields on the surface of land. The ice accumulations will also exhibit seasonal melt and flow directly into the ocean or drain into the ocean as part of seasonal overland flow. Very large amounts of frozen water will flow directly into the oceans as part of ice streams and glaciers with marine termination that form ice bergs.

Water may evaporate or transpire (return to the atmosphere) and precipitate many times through local and regional hydrological cycles but all water will eventually return to the ocean. Local and regional hydrological cycles can be very important to local and regional environments. Snow accumulations will melt when the temperature of the air above the snow surface reaches or exceeds the melting temperature of ice, 0° C. Liquid water will form and runoff occur when the temperature of the entire depth of snow accumulation reaches 0°C (The snow accumulation is said to be 'ripe'). The melting process may be accelerated with precipitation of warmer rain. Snow accumulations on plains regions, which are more-or-less at the same elevation, will melt at the same time and drain at the same time. Snow accumulations in mountainous regions will melt as the temperature at the different elevations reaches the melting point. The rate of melting and drainage will reach a maximum when the greatest snow-covered area is at or above the melting temperature and then gradually decrease.

A typical graph of overland flow in drainages that include both plains and mountainous regions is illustrated in Figure 6.2. As illustrated overland flow resulting from melting snow over plains regions will reach a maximum relatively quickly and will reduce to pre-melt conditions equally quickly. Overland flow resulting from melting snow over mountainous regions will reach a maximum more slowly and reduce to pre-melt conditions more slowly. Because snow accumulations over mountainous regions may be much greater than that on plains regions the volume of overland flow produced from the melting of snow accumulations from mountainous regions may be much greater than that of plains regions.

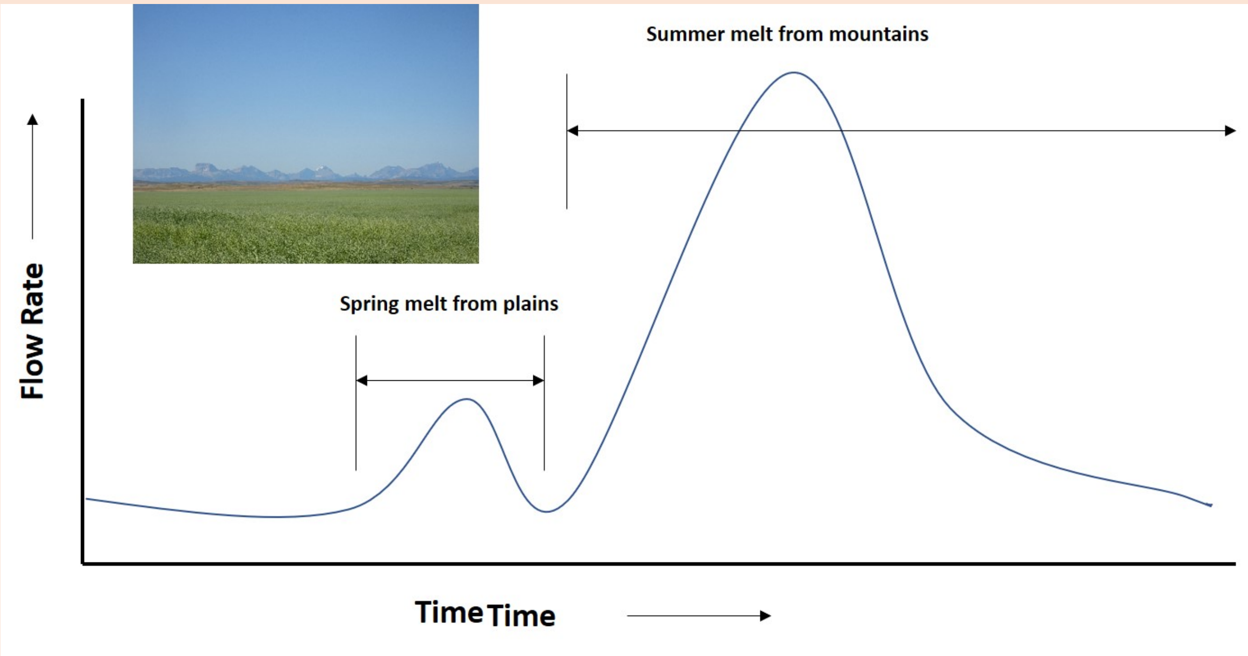

Figure 6.2 Graph showing surface runoff from melting snow from plains and mountainous regions.

The volume of snow melt and the manner with which it occurs has been predictable – particularly from mountainous regions. For this reason, humans have developed a dependency on the mountain melt for domestic and agricultural use. In some regions of the world mountain snow melt is captured using dams and reservoirs so that it can be gradually used for irrigation purposes or when the melt would be insufficient for domestic, municipal and industrial use. Melt water is often stored for generation of electricity.

6.8 Distribution of water on Earth

The distribution of water on Earth is shown in Figure 6.3. Note that 97% of the water is in the oceans (includes all forms of floating ice). The remaining 3% is divided between groundwater, 22%, and ice sheets, ice caps, ice streams, glaciers and inland seas, 77%. Very little is stored in rivers, lakes and the atmosphere. There is little opportunity for groundwater storage to change; but there is significant opportunity for water stored in ice sheets, ice caps, ice fields and glaciers to melt and become part of the oceans.

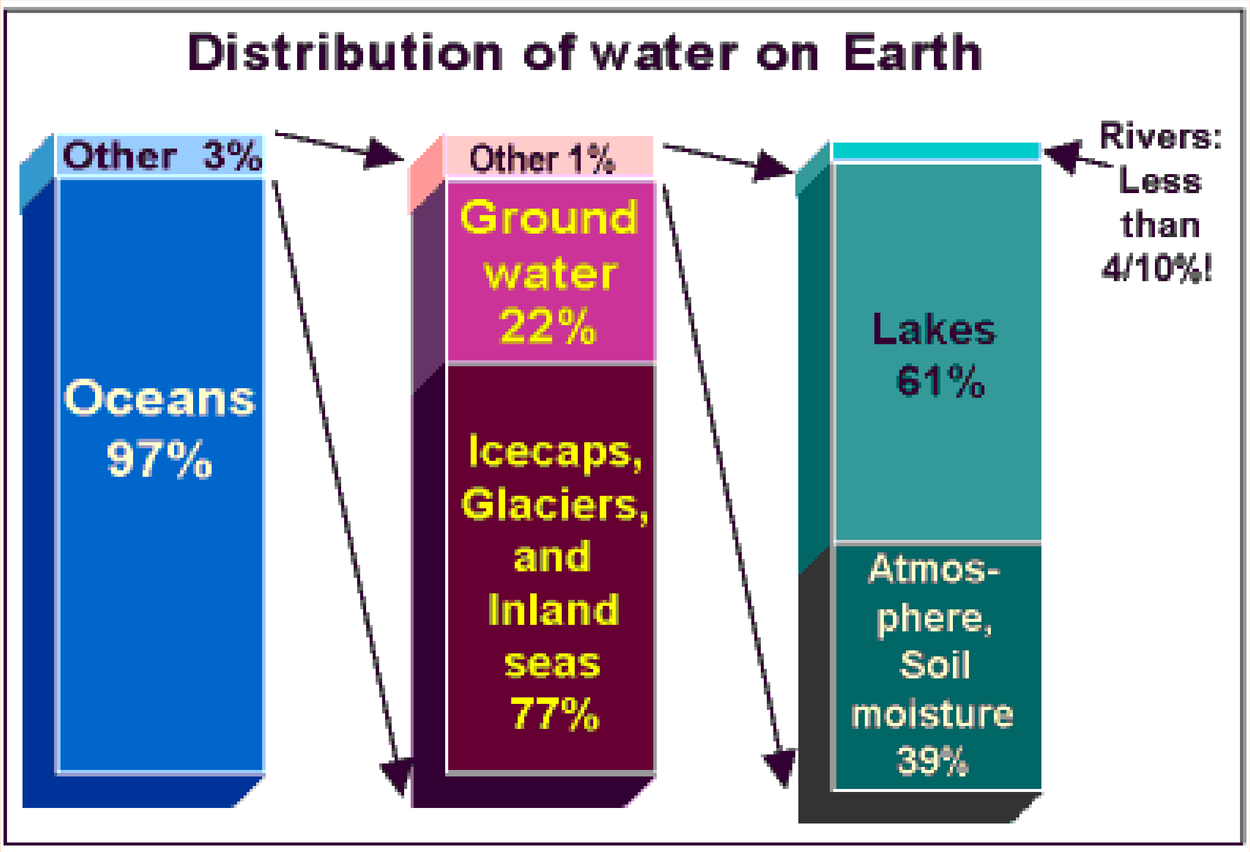

Figure 6.3 Distribution of water on Earth.

6.9 Ice caps, glaciers, ice streams, ice field, ice sheets, ice shelfs, sea ice

Ice caps are glaciers that cover an area of less than 50,000 square kilometres. See Figures 6.4 (a), (b) and (c). Ice caps that interconnected form an ice field. A glacier that is surrounded by mountain terrain is called a mountain glacier or alpine glacier. Glaciers that terminate in water may disintegrate to form ice bergs. Melt water from glaciers may form the headwater for streams and rivers which ultimately return the water to the ocean. Frequently the melt water will form a glacial lake which will overflow as it fills https://nsidc.org/cryosphere/icelights/2013/05/ebb-and-flow-glacial-lakes . The outflow capacity from a glacial lake must match the inflow rate. If it doesn't there is a danger of a glacial lake outburst which has the potential of damaging human activities downstream. The damage could include structures such as hydro-electric dams and their catastrophic failure. See video, https://www.youtube.com/watch?v=ZN8a-pP60wk .

Glaciers that flow directly into the ocean gradually break off in a process called calving. This is best explained by watching the video produced by NASA, https://www.youtube.com/watch?v=0QVVzFPChAU&feature=emb_logo.

Ice sheets have a surface area greater than 50,000 square kilometres. See Figure 6.5 and Figure 6.6. The most important examples are the Antarctic and Greenland ice sheets. They are also known as continental glaciers. The portion of the ice sheet that extends over water is known as an ice shelf.

Ice streams are a type of glacier flowing from an ice sheet (not to be confused with water flowing under or over the ice). Ice streams may flow into marine terminating glaciers or directly into the ocean itself. The flow of the ice stream may be slowed by a blocking ice shelf.
Ice shelves and ice streams disintegrate to form ice bergs.

Ice sheets and glaciers will gain or lose mass as a function of snow accumulation versus melting processes and iceberg calving.

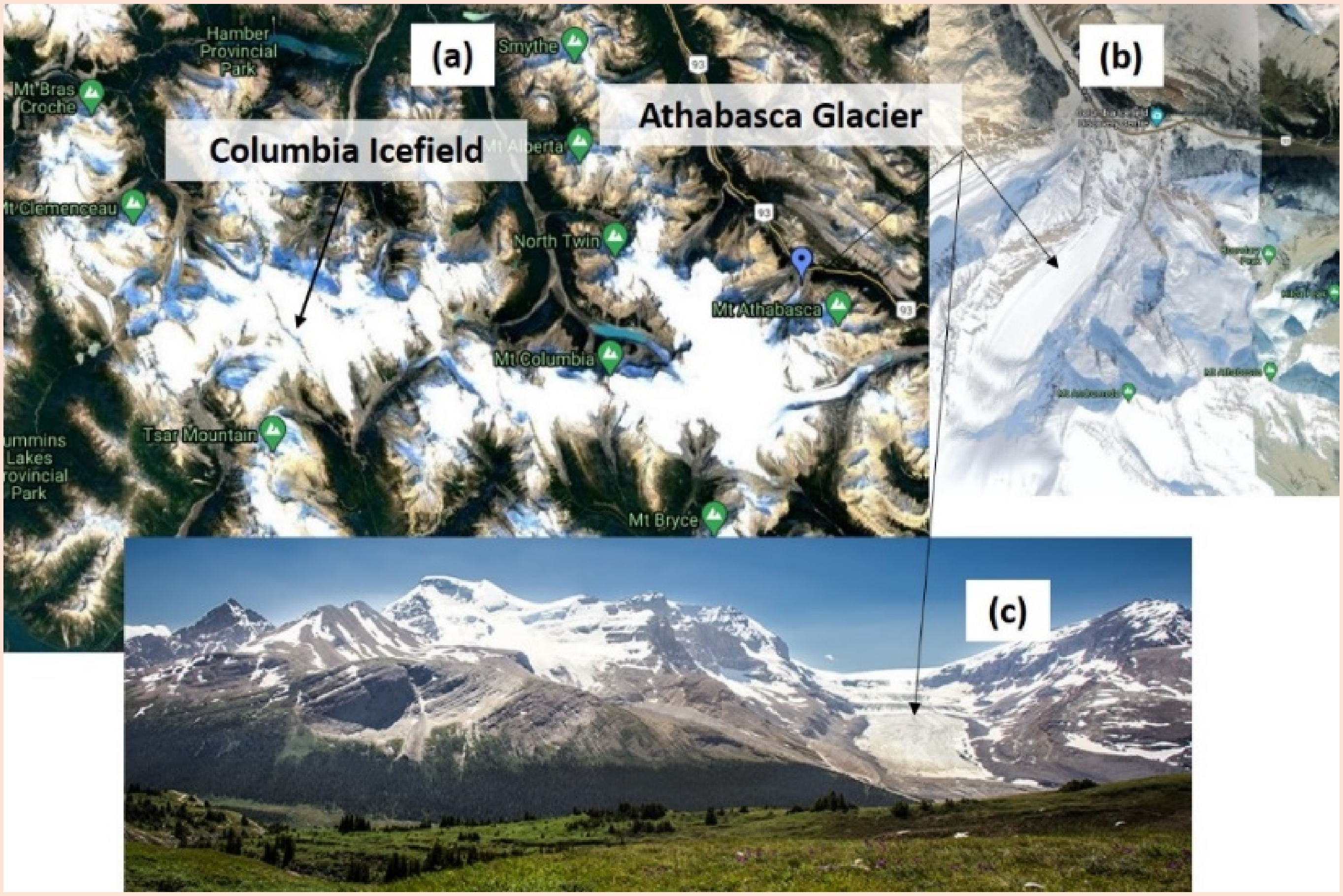

Figure 6.4 Columbia icefield, Canada and the Athabasca Glacier flowing from it.

Figure 6.5 Greenland ice sheet.

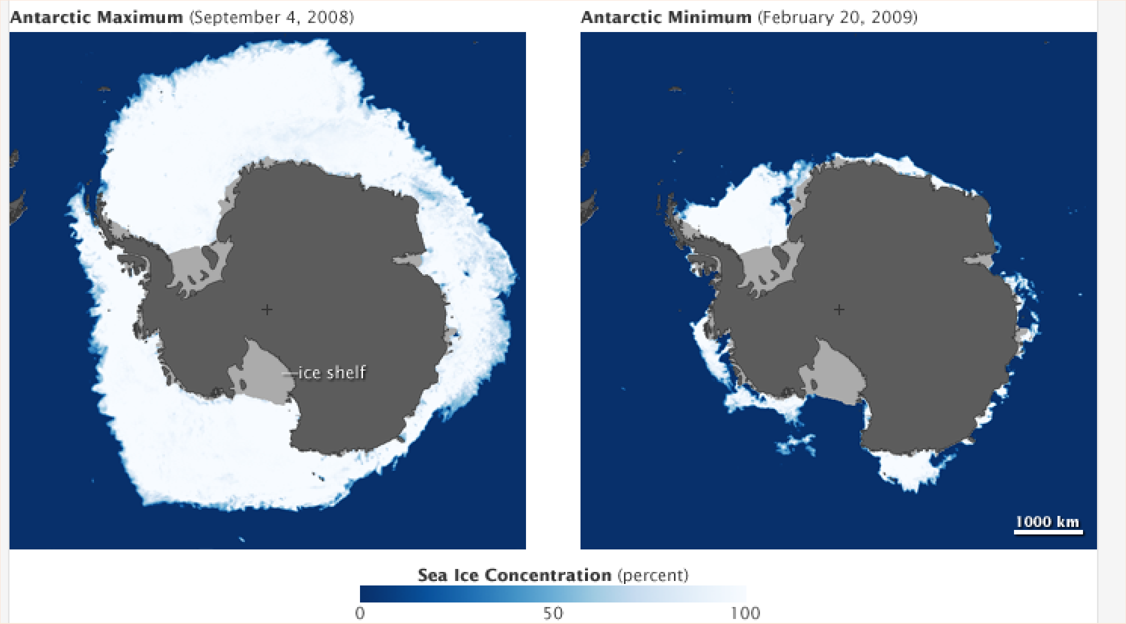

Figure 6.6 Antarctica ice sheet, sea ice and shelf.

Most floating sea ice is found in the Arctic. See Figure 6.7. The ice cover is divided into seasonal and permanent. Seasonal ice is formed during the winter months and melts during the summer. The permanent ice is replenished during the winter months and also melts during the summer. The area of permanent ice will increase or decrease with temperature of the atmosphere and ocean. Sea level is not affected by formation or melting of floating sea ice.

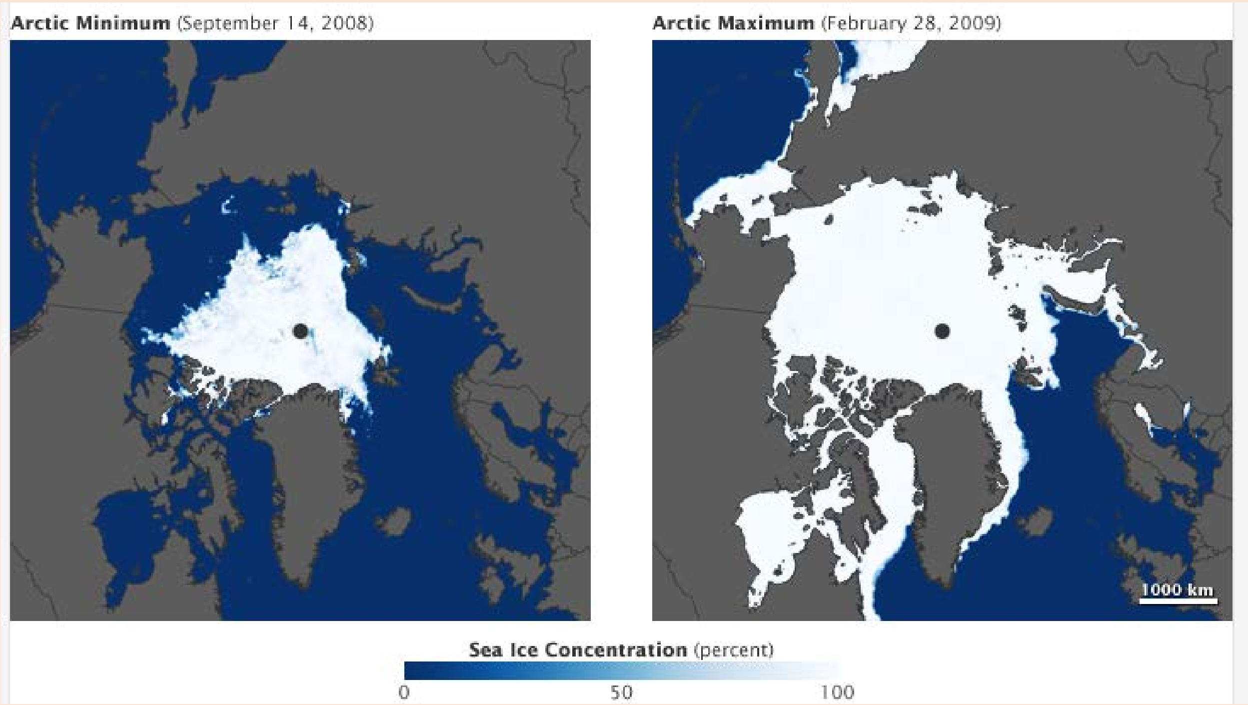

Figure 6.7 Floating Sea ice in the Arctic.

While the volume of water entering the ocean is little when compared to the volume of water already stored in the oceans, should it melt or flow into the oceans, it is sufficient to raise the ocean surface level by over seventy metres. The volume of water stored in the Greenland ice sheet and Antarctic ice sheet are the most important. Sea levels would increase by at least six metres as result of the Greenland ice sheet melting and flowing into the ocean and an increase in the order of sixty metres as a result of the Antarctic ice sheet melting and flowing into the ocean.

6.10 Isotopes of oxygen, hydrogen, deuterium and water

Water will occur naturally with two molecular weights depending on whether the hydrogen atoms are combining with an oxygen atom containing eight neutrons known as oxygen 16 or ten neutrons known as oxygen 18 (isotopes of oxygen). These isotopes should not be confused with heavy water or deuterium oxide, D_2O, where the oxygen atom combines with two hydrogen atoms that include a neutron as well as a proton forming an atom known as deuterium, D. Deuterium oxide is also naturally occurring but in very small quantities. Heavy water plays a very important role in the nuclear industry. Water molecules containing oxygen 18 are heavier and require more energy to evaporate and will release more energy when they condense. The ratio of the water containing oxygen 16 to oxygen 18 in the oceans is constant. The amount of water containing oxygen 18 evaporating from the ocean surface increases or decreases in response to the rising or falling temperature of the ocean surface and the air above it. Water containing oxygen 18 will be the first to condense.

6.11 Hydrologic data availability

Hydrological data includes everything identified in the hydrological cycle as shown in Figure 6.1. Meteorological data collection and archiving is discussed in Chapter 3. All other data that describes water occurrence, in any form, in terms of volume or movement is termed hydrometric data. Important examples of hydrometric data include: river discharge, depth, and sediment loading, lake and reservoir depth, surface area and volume, occurrence of ice cover on rivers and lakes including thickness, timing of formation and breakup and formation of ice jams, and snow accumulation on watersheds, glacier growth and ablation, ice field growth or depletion, sea level, wave height and possibly groundwater/ aquifer monitoring. The variation of these parameters will be similar in nature to that discussed in Section 3.1. The collection and archiving of hydrologic data are typically the responsibility of individual national governments. They will try to use the best available methods to collect the data and make most of it available for free to the public.
In Canada hydrometric data is available through the web site, https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html .

6.12 Forecasting

Three types of forecasting are commonly used: stochastic, real-time and distributed.

6.12.1 Stochastic forecasting

Stochastic forecasting is based on the statistical analysis of historical data. All hydrologic parameters may be analyzed using stochastic methods. Stochastic forecasting depends on the availability of a significant period of historical data obtained during a stable climatic period. It is preferable to have thirty pieces of data or more - thirty years or more if annual data is used.

Stochastic forecasting is particularly useful for the analysis of historical data of water movement in a watershed, the area contributing water to a specific location along a river or steam or the hydraulic experience near a water body. The most used tool is frequency analysis that is similar in every respect to that described in Section 3.4. The information is used to design infrastructure in the vicinity of river, streams and reservoirs such as bridges and culverts, pipeline crossings, spillways on dams and other diversion structures and other infrastructure that may contact water bodies such as piers, causeways and shorelines. Stochastic forecasting is used extensively to manage water resources by assessing water availability for potential consumers of the water resource such as for municipal water supply, storm water management, flood preparation or prevention, irrigation, industry, infrastructure design, recreation and maintenance of in-stream environments. An important use of stochastic forecasting is the delineation of flood plains, areas inundated by river flow, that allow management of human activities that would encroach on river and lake perimeters.

6.12.2 Real-time forecasting

Real-time forecasting is used operationally to prepare for imminent river flow or other impactful events such as storm surges and large waves.

Real-time forecasting of discharges from watersheds is used to predict river flow rate and depth and the timing of events using watershed models of varying complexity whose primary input is real-time data on rainfall (amount and areal distribution over watershed) and similarly snow melt if required real-time meteorological data is also available. Models are used which attempt to determine how much of the precipitation or snow melt will enter the groundwater system (and eventually reach the river and stream channels) and the rate and manner with which it will flow directly into the river and stream channels. Real-time forecasting uses models that can be considered semi-empirical in that they maximize the analysis of available historical data and then use some form of stochastic process to ‘fit’ model output to observed events. Movement of flows through river and streams and through lakes and reservoirs make extensive use of modelling of the hydraulics of water flow (hydraulic routing) which is perhaps the most deterministic element of the modelling process.

Real-time forecasting of river flow makes extensive use of real-time flow measurements (gauging) to confirm predictions.   Very large watersheds with extensive gauged drainage systems (rivers and streams) may use hydraulic routing as the primary method of forecasting once watershed contributions to runoff are established.

Another important example of real-time forecasting is the prediction of storm surges and wave set-up on land areas adjacent large bodies of water such as the ocean, seas, large reservoirs and lakes. In northern regions this can also include ice run-up on land adjacent large rivers and lakes during spring break-up.

6.12.3 Distributed models

Distributed models require the knowledge and availability of all the underlying factors determining the value of the parameter be forecasted. Weather forecasting as discussed in Section 3.4 is a good example.

Another use of distributed forecasting is distributed hydrologic modelling. These models attempt to take into account all of the surface physical, vegetative, groundwater and hydraulic characteristics of a watershed. The inherent assumption being that the affects on water flow from each of these characteristics is known and can be successfully integrated. It follows that knowing where precipitation events occur it is possible to predict the nature of runoff events, surface and groundwater. It is possible to predict how changes in land use will affect the nature of runoff. It is also possible to use information from a frequency analysis of precipitation events over a watershed to generate a frequency analysis of river flow fed from the watershed. Randomly generated data from the same statistical analysis could be used in many simulations to produce the same information (Monte Carlo technique). The affects of land use changes could be similarly used. Unfortunately, the data requirements for distributed hydrologic models are very large and are infrequently, if ever, met.

A somewhat less complex form of distributed forecasting is the use of information on river flow and physical characteristics to predict sediment transport, erosion and scour. The flows used are typically those identified in a frequency analysis. The information is used to determine the depth of pier support for bridges, depth of pipe lines crossing rivers and streams, river bank armouring requirements, bed scour below in-stream reservoirs and useful reservoir life.

6.13 Flood Plain Delineation

Flood plains are the areas adjacent a river or stream that is periodically inundated (flooded) when the flow in the channel overflows its banks. The land in the flood plain may be used for human activities if the risk of flooding is considered acceptable. Land on the flood plain is considered valuable for human use including habitation, business, industry, agriculture and other uses. It is desirable to allow human use of as much of the flood plain as possible. Risks of one flooding event every one hundred years is frequently adopted and is called the one in a one-hundred-year event or a 1:100-year event. The 1:100-year event is determined by the level of risk companies, governments and other organizations are willing to take before under righting (insuring for loss or damage) or compensating owners for damages caused by flooding.

A typical river valley is shown in plan view in Figure 6.8 and cross-section view in Figure 6.9. The river is located in a river valley. The land above the valley is known as the bench land. The river has what is called the bank-full flow rate at which point any additional flow will flow over the banks and on to the flood plain. The surface elevation of flooding of the flood plain that would result from a 1:100-year river flow rate is shown in dashed lines in Figure 6.8. Figure 6.9 illustrates the relationship between the surface elevations of the in-stream flow, bank-full flow, flood plain, valley wall and bench land and the surface elevation of the extent of flooding of the flood plain for the 1:100-year river flow. Human development is allowed on the flood plain where the surface elevation exceeds that of the 1:00-year flow; that is between the dashed line and the valley wall. Any development in the area between the river and the surface elevation of the 1:100-year event may not be allowed or compensated for when flooding occurs.

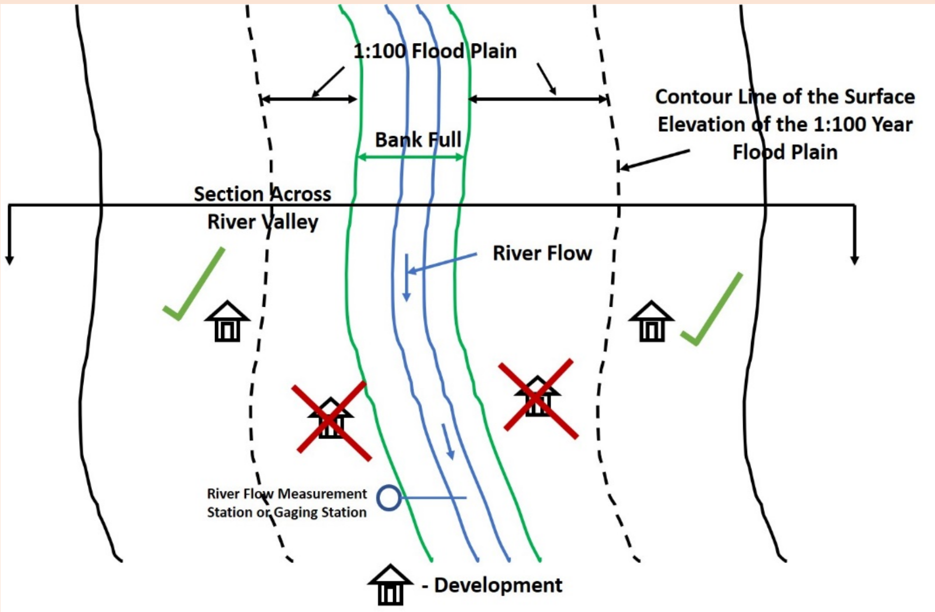

Figure 6.8 Plan view of a typical river valley.

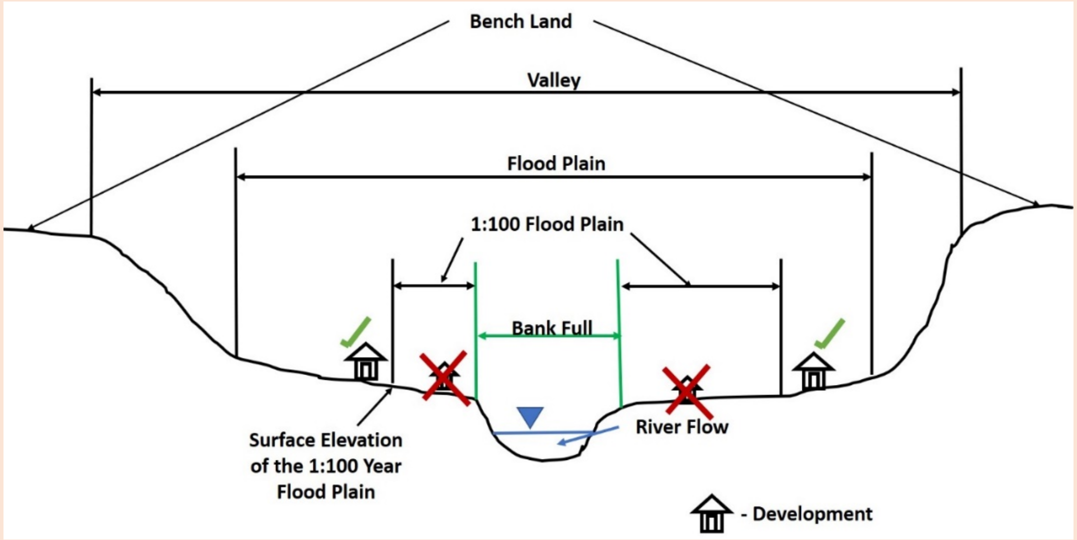

Figure 6.9 Cross-section view of typical river valley. See https://www.nrcan.gc.ca/science-and-data/science-and-research/natural-hazards/flood-mapping-types-and-process/24264 for description of flood mapping process.)

The question is: 'How is the surface elevation of the 1:00-year event determined?'

The parameter of interest is flow in the river. It is measured using a river flow measurement station or hydrometric station (See https://geology.com/articles/gaging-station.shtml). The surface elevation of water is related to the flow of water as shown in Figure 6.10. (This graph may be plotted with the vertical axis showing river flow and the horizontal axis showing surface elevation.) The flow rate will vary significantly over a one-year period similar to that shown in Figure 3.1 reflecting the effects of snow melt, glacier melt and rainfall events that occur over a one-year period. As mentioned earlier, in Canada, this information is available from the web site, https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html .

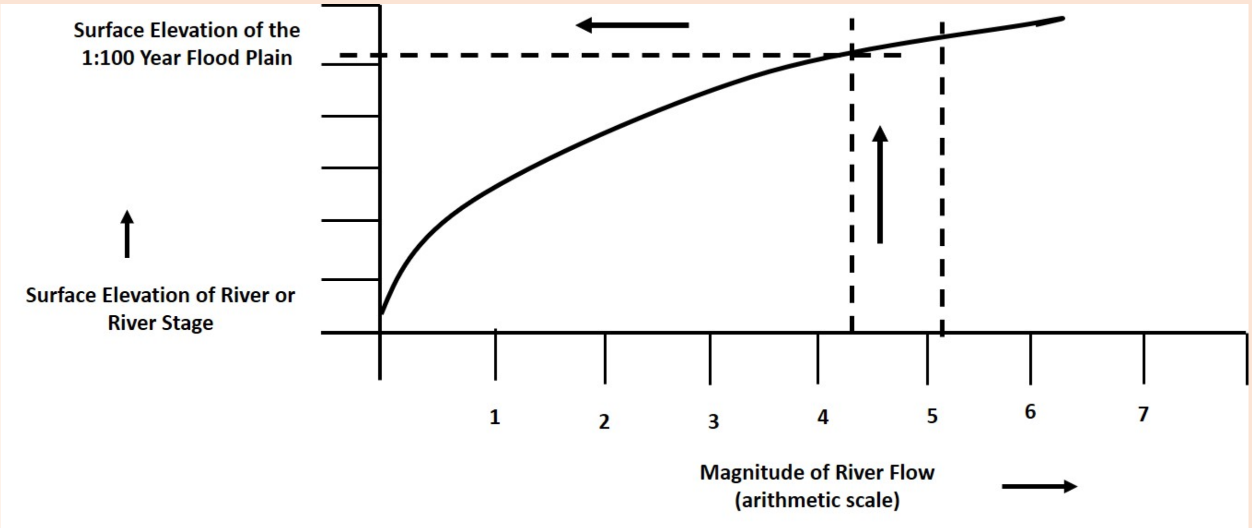

Figure 6.10 Surface elevation of water in a river (river stage) vs flow of water in river (rating curve https://openecodatalab.github.io/Hydrology-Online/hydrology/7_rating_curve/7_rating_curve.html)

The parameter chosen in this instance is the maximum daily flow in the river in a one-year period – one value per year. Thirty years of flow records will supply thirty parameters to analyse. These parameters are related to frequency of occurrence as shown in Figure 6.11. The information collected at one point along the river can be extrapolated a considerable distance upstream and downstream using several readily available hydraulic analyses methods.

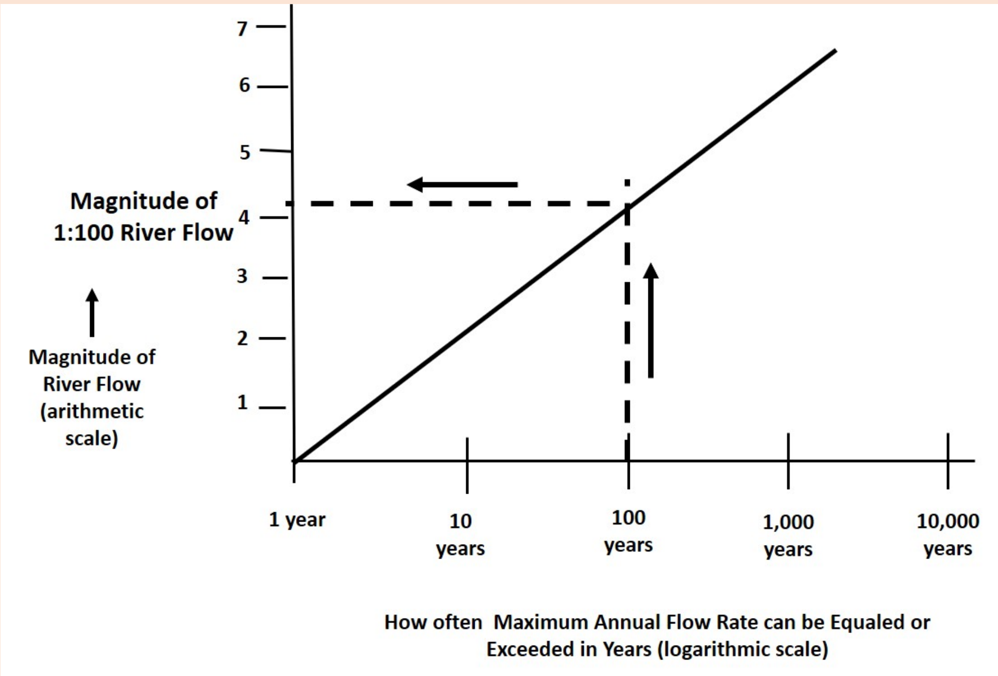

Figure 6.11 Frequency analysis of maximum annual river flow (flood frequency curve
https://pubs.usgs.gov/tm/04/b05/tm4b5.pdf
https://serc.carleton.edu/hydromodules/steps/166250.html)

The first step is to determine the magnitude of the 1:100-year river flow from the graph shown in Figure 6.11. The value is taken to Figure 6.10 to determine the surface elevation this corresponds to. The value of the surface elevation can then be used to define acceptable areas for development corresponding to the 1:100-year flow as shown in Figures 6.8 and 6.9. Areas above the surface elevation corresponding to the 1:100-year event are considered acceptable for development – below not acceptable.

Other flood events can be estimated. If the data used is based on only 30 years of observations, events with return periods of 1:30-years are more reliable. Clearly, the 1:100-year event must be based on extrapolating the curve in Figure 6.11 from the 1:30-year return. This is normal since there is a limited period over which hydrometric data has been collected and there is no choice but to use the extrapolated curve for determinations greater than 1:30-years. Users of this technique understand the uncertainties and limitations of these analyses.

This analysis is very, very important. Considerable economic development, worldwide, depends on the results of these analyses. The utility of the analyses depends on the availability of suitable river flow data collected during periods of stable climatic conditions with the view that the SAME stable climatic conditions will continue into the future.

Distributed techniques can also be used if sufficient input data is available but still must be calibrated (confirmed) using observed data. These methods may be of great value if real-time models are available and considered reliable.

6.14 Information support

Key web sites:

1. Hydrology and water resources. https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap4.pdf

2. Hydrologic cycle. http://www.physicalgeography.net/fundamentals/5c_1.html

3. Cloud physics and their role in climate models, Prof. Ellie Highwood, guest post in the newsletter, 'Carbon Brief', https://www.carbonbrief.org/guest-post-why-clouds-hold-key-better-climate-models.

4. Clouds, journal 'Nature Climate Change', https://www.nature.com/articles/s41558-021-01038-1 and newsletter, 'Carbon Brief', https://www.carbonbrief.org/cooling-effect-of-clouds-underestimated-by-climate-models-says-new-study?utm_campaign=Feed%3A%20carbonbrief%20%28The%20Carbon%20Brief%29&utm_content=20210604&utm_medium=feed&utm_source=feedburner

5. Glacial lakes. https://nsidc.org/cryosphere/icelights/2013/05/ebb-and-flow-glacial-lakes

6. Antarctic glaciers. http://www.antarcticglaciers.org/

7. Ice field. https://en.wikipedia.org/wiki/Ice_field#:~:text=An%20ice%20field%20%28also%20spelled%20icefield%29%20is%20a,there%20is%20sufficient%20precipitation%20for%20them%20to%20form

8. Global volume of land ice and how it is changing. http://www.antarcticglaciers.org/glaciers-and-climate/what-is-the-global-volume-of-land-ice-and-how-is-it-changing/

9. Columbia Icefield area and Athabasca Glacier. https://www.pc.gc.ca/en/pn-np/ab/jasper/activ/itineraires-itineraries/glacier-athabasca

10. Ice fields and ice caps. https://www.nps.gov/articles/icefieldsicecaps.htm

11. Glaciers and icecaps. https://www.usgs.gov/special-topic/water-science-school/science/glaciers-and-icecaps?qt-science_center_objects=0#qt-science_center_objects

12. Quick facts on ice sheets. https://nsidc.org/cryosphere/quickfacts/icesheets.html

13. Greenland ice sheet today. http://nsidc.org/greenland-today/

14. Antarctica. https://en.wikipedia.org/wiki/Antarctica

15. What is Antarctica? https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-antarctica-k4.html

16. Hydrometric data Canada. https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html

17. Description of flood mapping process. https://www.nrcan.gc.ca/science-and-data/science-and-research/natural-hazards/flood-mapping-types-and-process/24264

18. Stream gaging station. https://geology.com/articles/gaging-station.shtml

19. Description of stage – discharge, rating curve or surface elevation vs discharge curve https://openecodatalab.github.io/Hydrology-Online/hydrology/7_rating_curve/7_rating_curve.html

20. Description of flood frequency curve. https://pubs.usgs.gov/tm/04/b05/tm4b5.pdf and https://serc.carleton.edu/hydromodules/steps/166250.html

13. Ice shelves. https://nsidc.org/cryosphere/sotc/iceshelves.html

14. Sea level rise from ice sheets track worst-case climate change scenario. https://www.sciencedaily.com/releases/2020/08/200831112101.htm

15. Thwaites glacier. https://en.wikipedia.org/wiki/Thwaites_Glacier

16. Ice stream. https://en.wikipedia.org/wiki/Ice_stream#:~:text=A%20fast%2Dmoving%20ice%20or,are%20a%20type%20of%20glacier.&text=Most%20ice%20streams%20have%20some,base%2C%20which%20lubricates%20the%20flow.

17. Global ice viewer. https://climate.nasa.gov/interactives/global-ice-viewer/#/

18. Glacier. https://www.nationalgeographic.org/encyclopedia/glacier/

19. Glacier. https://en.wikipedia.org/wiki/Glacier

20. Historical hydrometric data Canada. https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html

Video:

1. How a glacier melts and calves into the ocean, NASA. https://www.youtube.com/watch?v=0QVVzFPChAU&feature=emb_logo

2. The most dangerous lake in Nepal. https://www.youtube.com/watch?v=ZN8a-pP60wk

3. Imja Lake: A story of climate adaptation in Nepal. https://www.youtube.com/watch?v=z7GKW-u-Gg4

4. Glacial outburst incident in Garhwal on 7th February 2021., https://www.indiatoday.in/india/video/glacier-burst-leads-to-massive-flash-flood-in-uttarakhand-1766802-2021-02-07