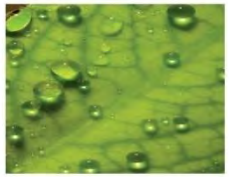
Southern Lakes Enhanced Storage Workshop Series

INTRODUCTION TO GROUNDWATER

NOVEMBER 26, 2011

Groundwater Workshop Outline

- **Overview of the Project Concept**

  Discussion & questions

- **Introduction to Groundwater**
  1. Why are we talking about groundwater?
  2. Groundwater fundamentals
  3. Surface water/groundwater interaction

  Discussion break

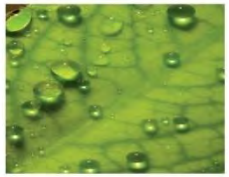
- **Scope of the Investigations**
  1. Purpose
  2. Groundwater monitoring
  3. Property surveys

  Discussion break

- **Preliminary Assessment of Effects to Shallow Groundwater**

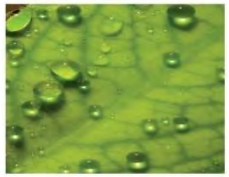
  Concluding Discussion

We are here

2.1 Why Are we Talking About Groundwater?

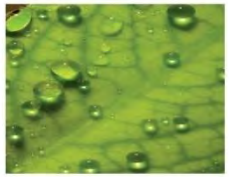
- High groundwater levels potentially affecting private properties was initially identified as a concern by residents early on in the scoping of the studies in 2009.
- Areas of interest were initially the low-elevation properties in Army Beach and S. M'Clintock.
- Subsequently other property owners on Marsh & Tagish Lakes identified similar interests.
- This is an existing conditions that was probably not a concern for most residents until it came to their attention during the 2007 flood.

2.1 Why Are we Talking About Groundwater, continued?

The question is *"will changed lake levels affect groundwater and specifically at private properties?"*

But to look at this question, we must first have an understanding of this mysterious thing called "groundwater"….

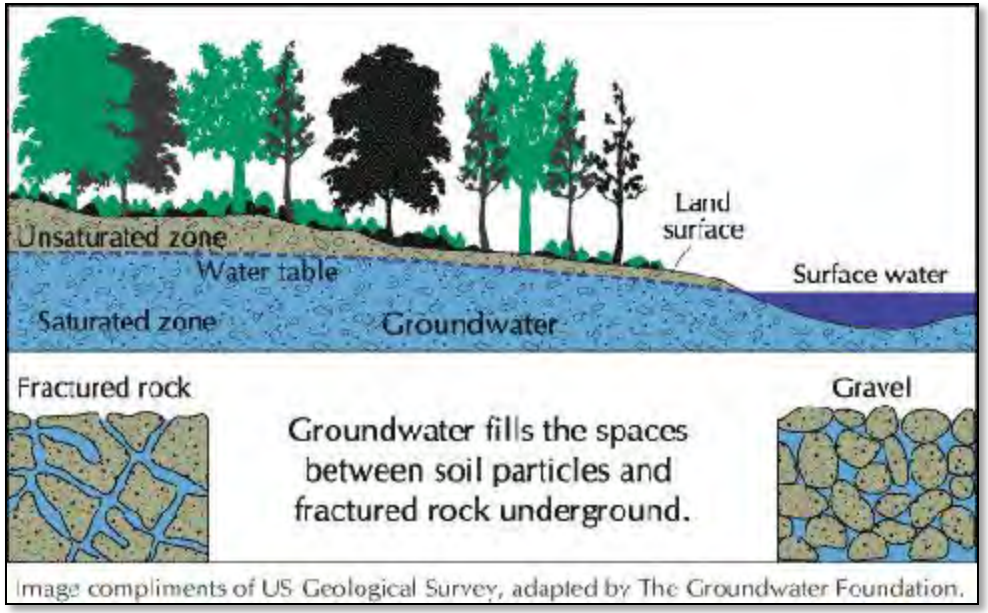



2.2 Groundwater Fundamentals

- What is groundwater?
- Regional groundwater systems.
- How does groundwater flows, and what controls groundwater flow?
- How fast does groundwater move?

2.2 Groundwater Fundamentals – What Is Groundwater?

- Groundwater is water below the ground surface. It is water filling the voids, or **pore spaces**, between grains of sand, gravel, silt and clay, or filling cracks in rock.



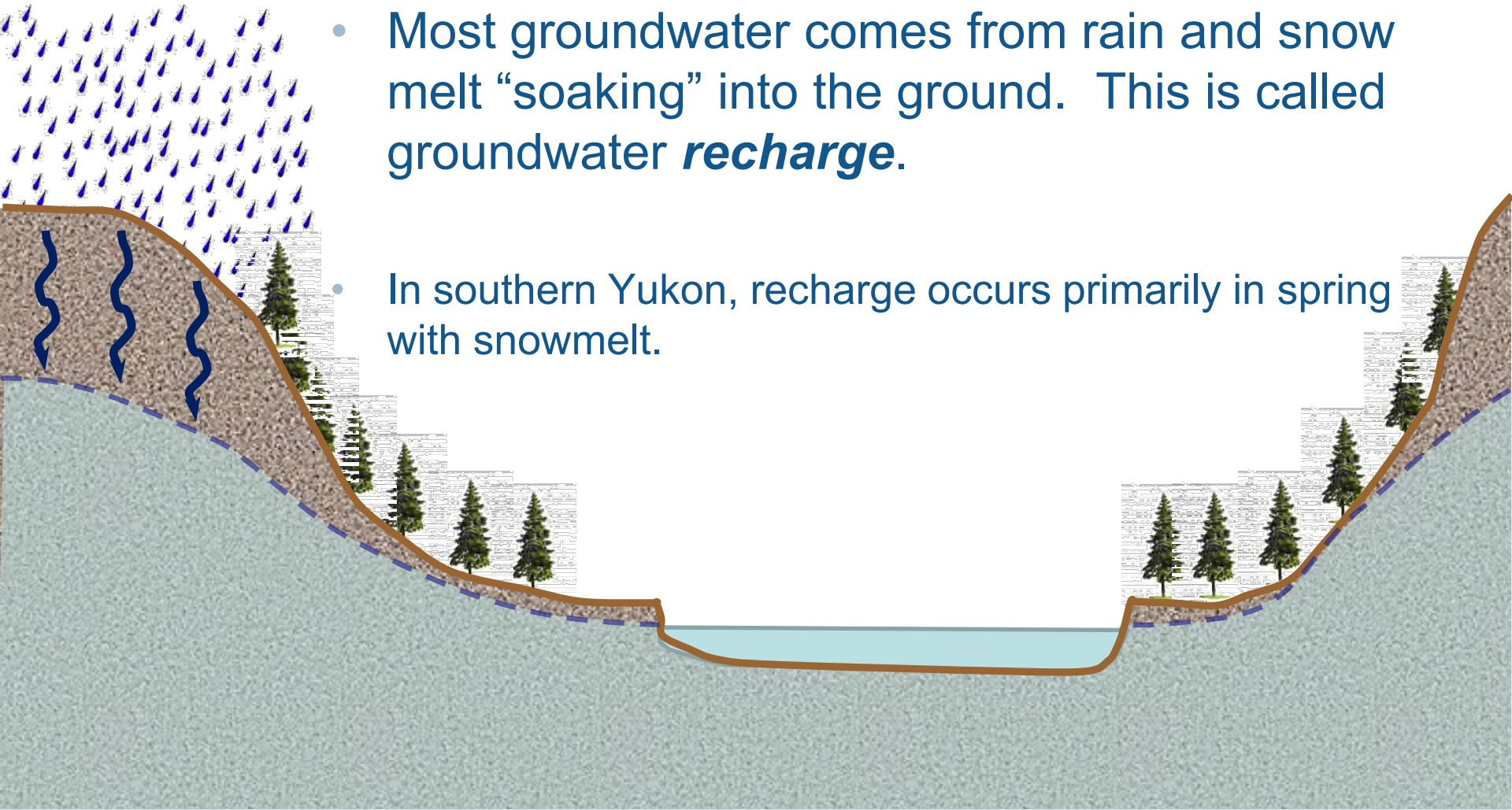
2.2 Groundwater Fundamentals – What Is Groundwater?

- Groundwater is NOT an underground river

- It is more like the water filling the spaces between aquarium gravel.

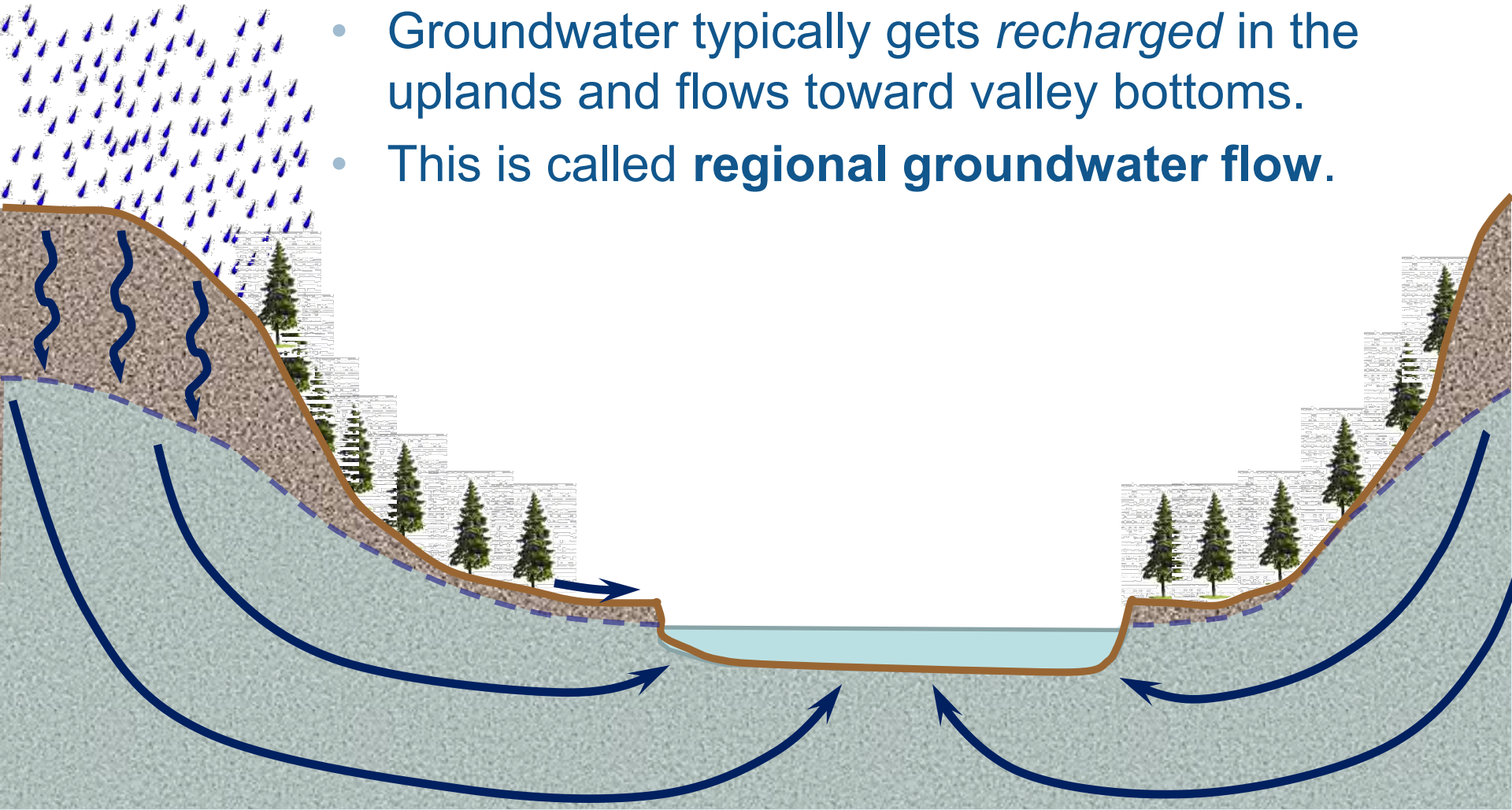
2.2 Groundwater Fundamentals – Where Does Groundwater Come From?

- Most groundwater comes from rain and snow melt "soaking" into the ground. This is called groundwater ***recharge***.
- In southern Yukon, recharge occurs primarily in spring with snowmelt.



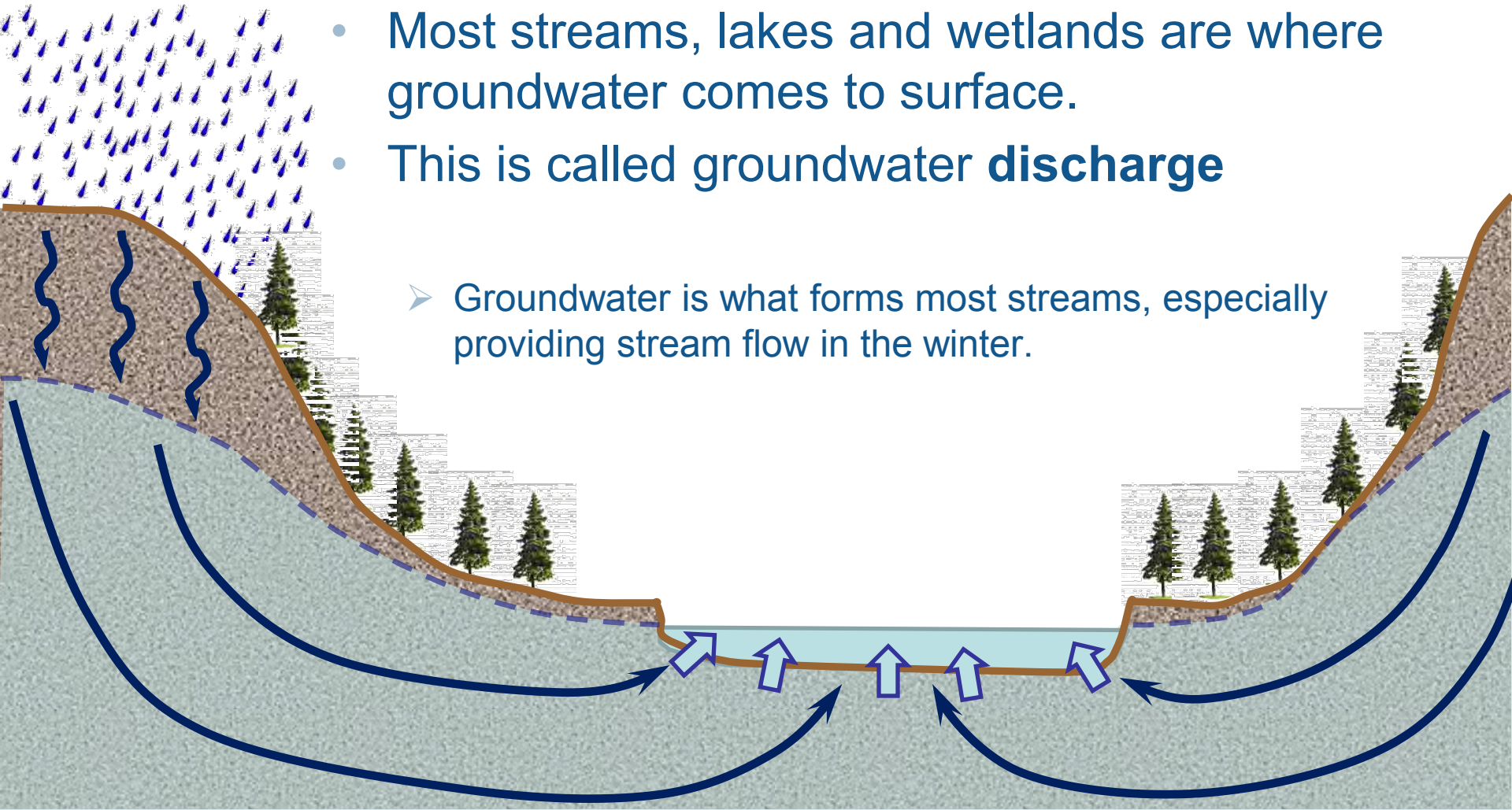
2.2 Groundwater Fundamentals – Where Does Groundwater Go?

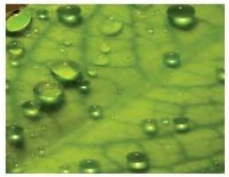
- Groundwater typically gets *recharged* in the uplands and flows toward valley bottoms.
- This is called **regional groundwater flow**.



2.2 Groundwater Fundamentals – Where Does Groundwater Go?

- Most streams, lakes and wetlands are where groundwater comes to surface.
- This is called groundwater **discharge**
  - Groundwater is what forms most streams, especially providing stream flow in the winter.



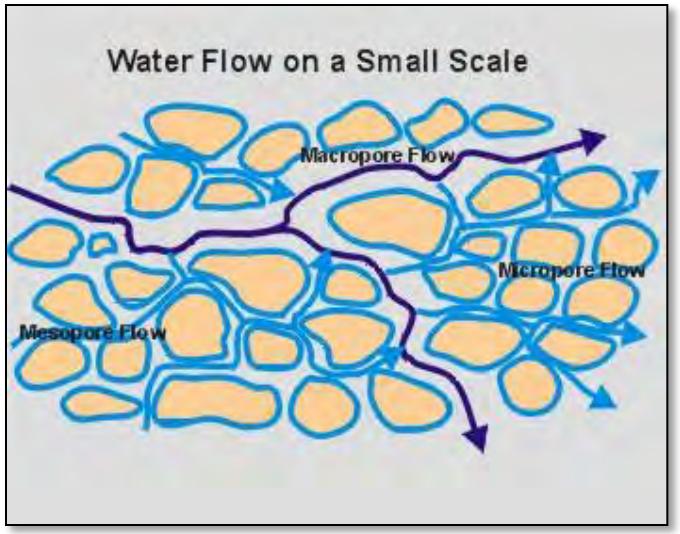
2.2 Groundwater Fundamentals – How Fast Does Groundwater Flow?

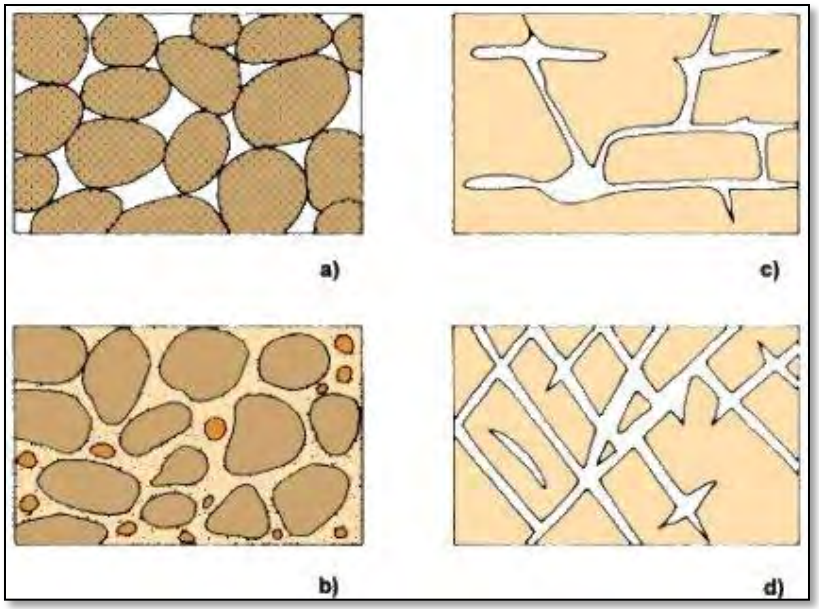
- Groundwater moves VERY slowly.
- Groundwater can flow from centimeters to tens of meters per year.
- **“**Fast” groundwater flow is hundreds of meters per year.
- This means groundwater trends can be monitored, observed and predicted – it is not like surface water which can change very quickly.
- This also means groundwater reacts very slowly to changes.

2.2 Groundwater Fundamentals – What controls how groundwater moves?

- **Permeability** is the measure of how easily a fluid can move through the earth. If the fluid is groundwater, we refer to this as **hydraulic conductivity.**

- *Permeability* is controlled by the spaces and connectivity of those spaces in the soil and rock.

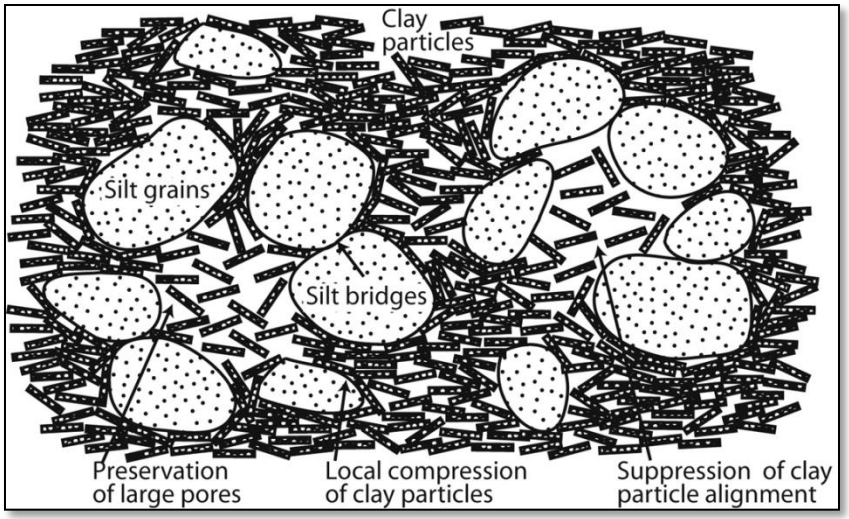




2.2 Groundwater Fundamentals – What controls how groundwater moves?

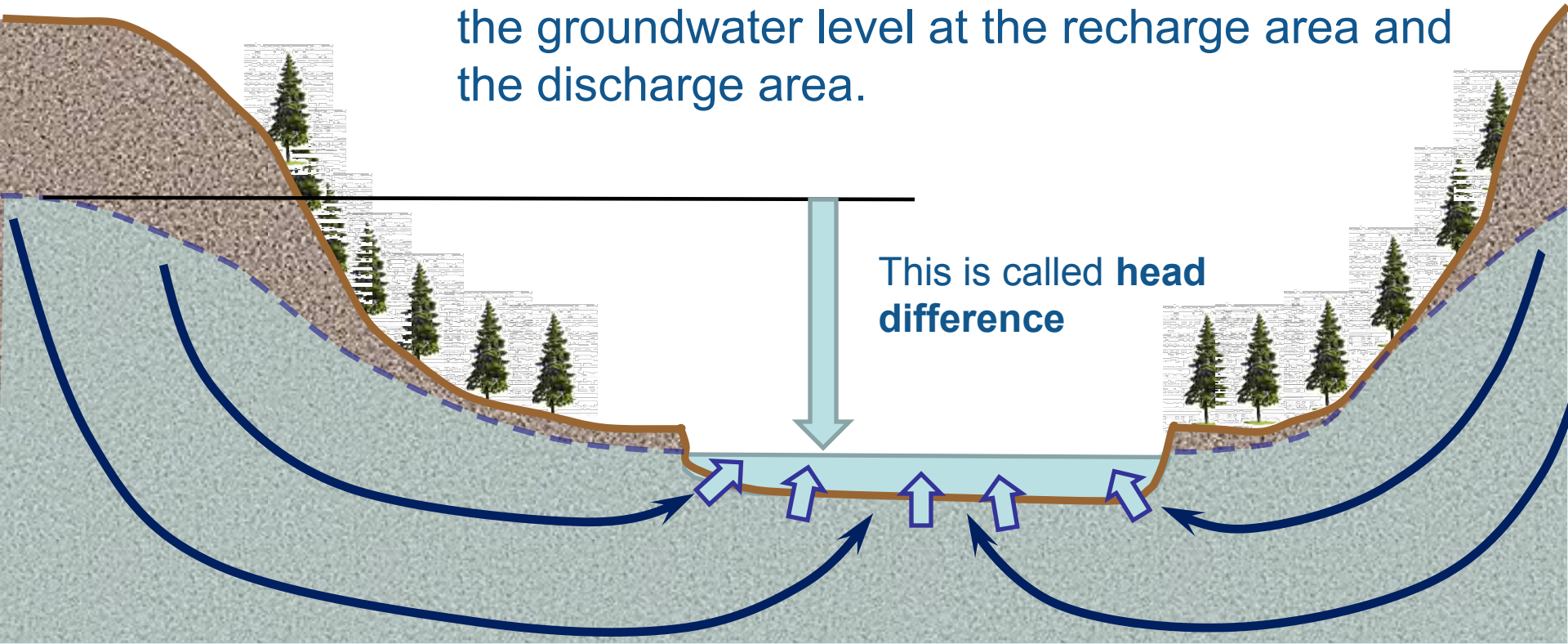
- Gravels and sand are highly *permeable* and allow water to flow "quickly" through the soil.
- Silt, clay and glacial till have low *permeability* because they are fine grained.

Fine grained soils and glacial till have poorly connected pore spaces which makes groundwater flow slow.



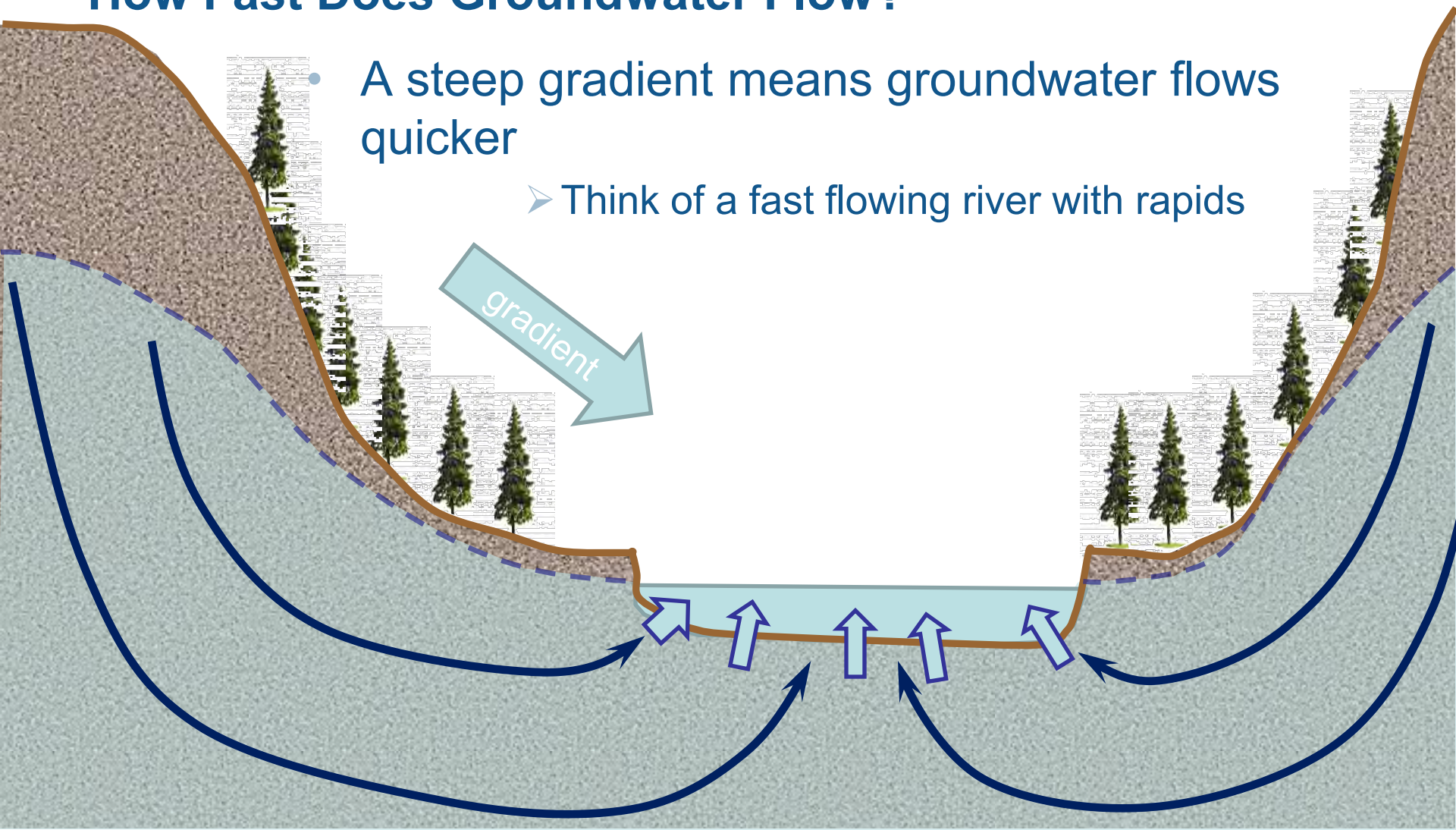
2.2 Groundwater Fundamentals – How Fast Does Groundwater Flow?

- The second factor governing groundwater flow is **gradient**.
  - *Gradient* is the elevation difference between the groundwater level at the recharge area and the discharge area.



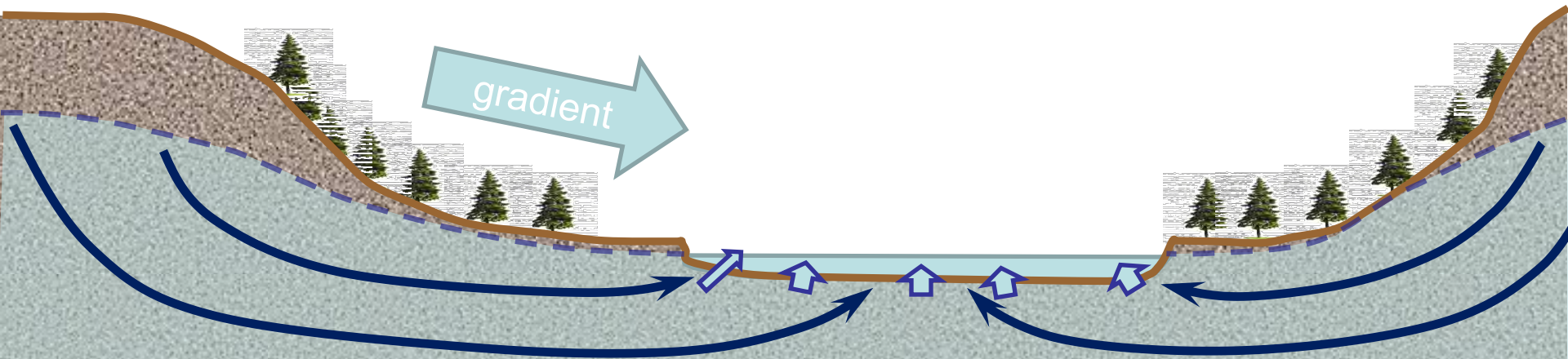
2.2 Groundwater Fundamentals – How Fast Does Groundwater Flow?

- A steep gradient means groundwater flows quicker
  - Think of a fast flowing river with rapids



2.2 Groundwater Fundamentals – How Fast Does Groundwater Flow?

- A low gradient means groundwater flows slowly
  - Think of a slow, meandering river



2.2 Groundwater Fundamentals Summary

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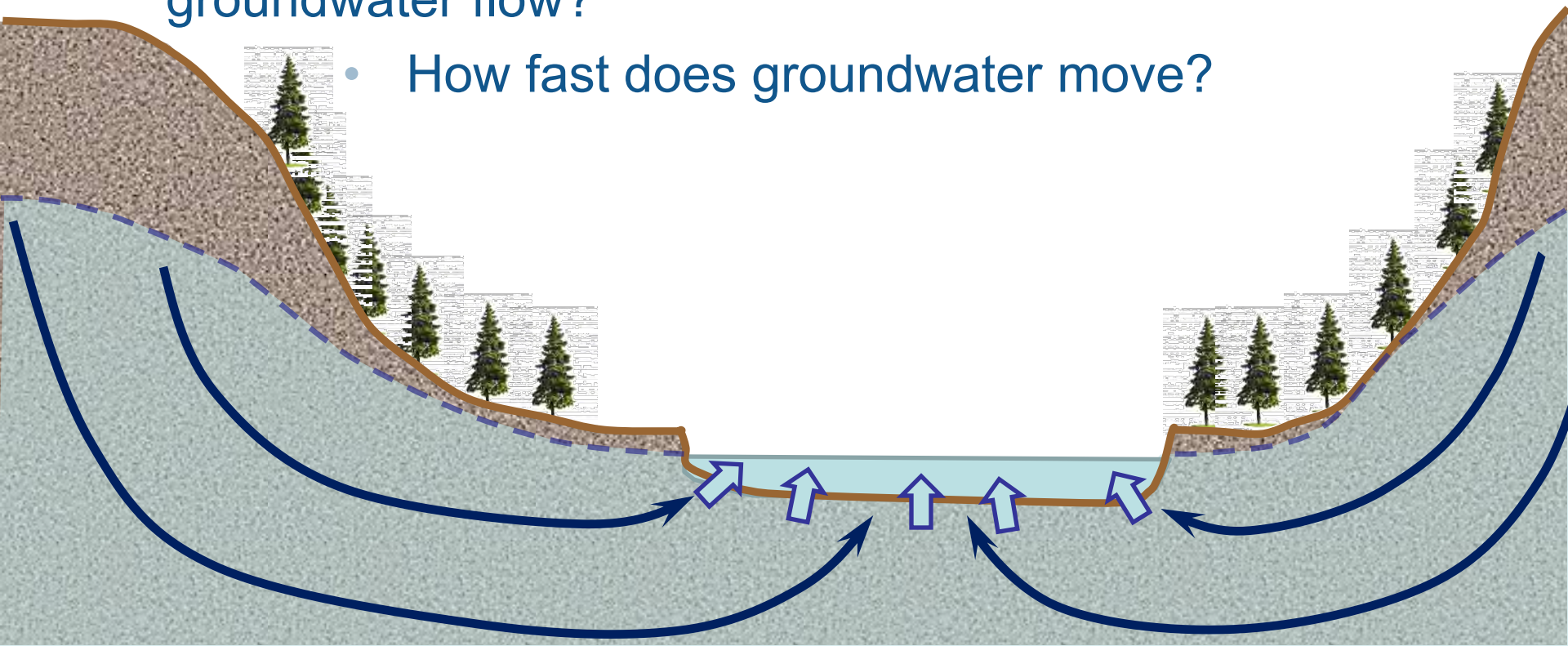
- How does groundwater flows, and what controls groundwater flow?
  - How fast does groundwater move?

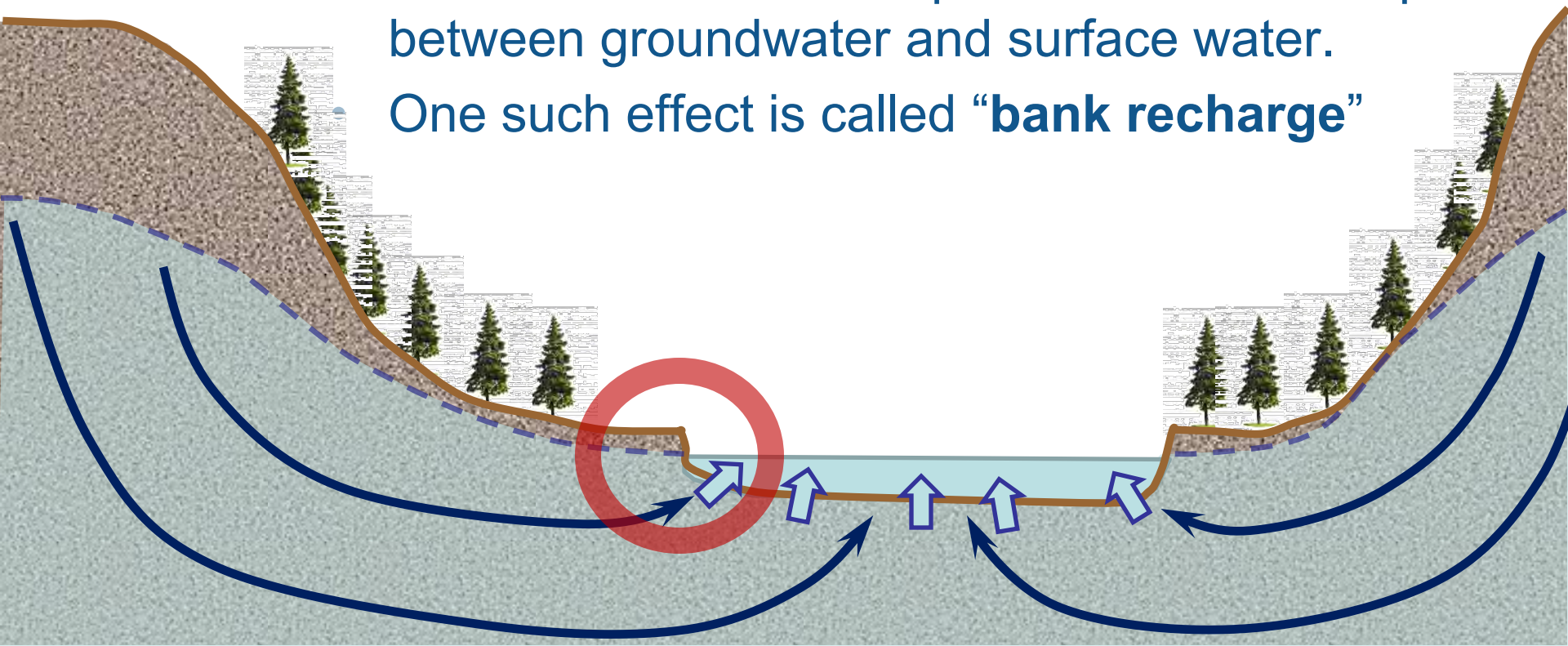


2.3 Groundwater / Surface Water Interactions

- Local groundwater flow and bank recharge
- How does groundwater / surface water interaction affect private property improvements currently?
- What is not effected by groundwater / surface water interactions.
- Summary of the interaction pathway.

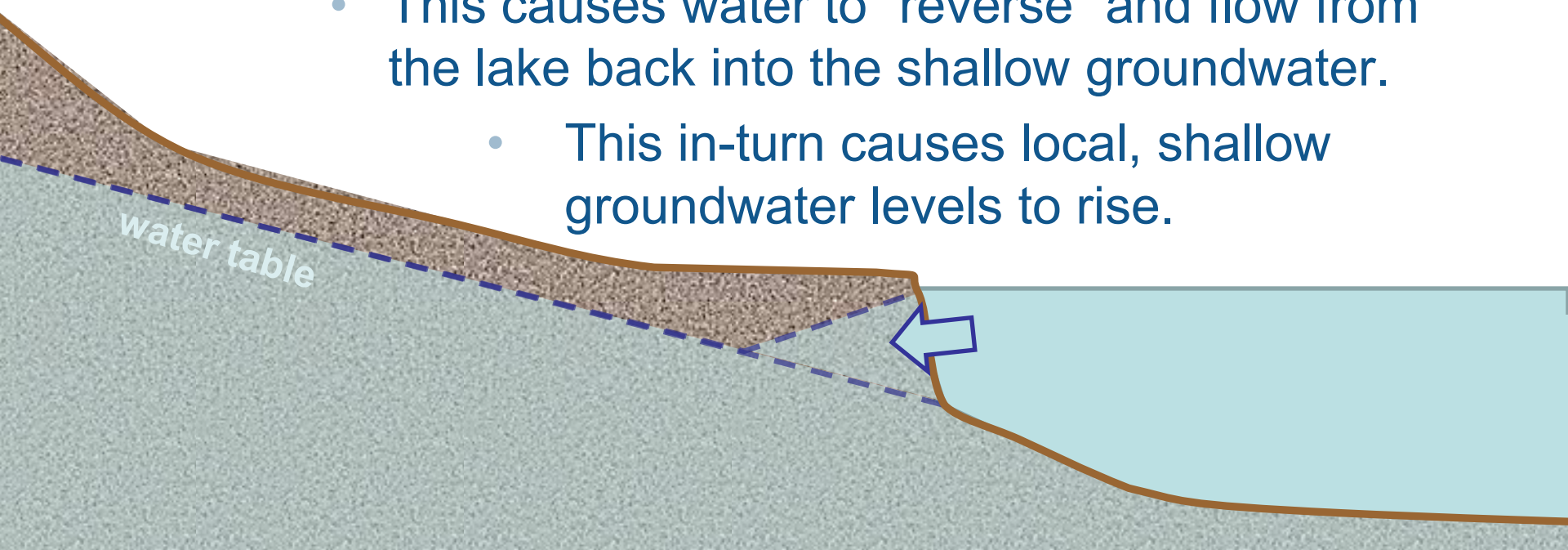
2.3 Groundwater / Surface Water Interactions – Local Groundwater Flow and Bank Recharge

- Water levels in lakes and river can change quickly relative to groundwater levels.
- This can create an complex inter-relationship between groundwater and surface water.
- One such effect is called "**bank recharge**"



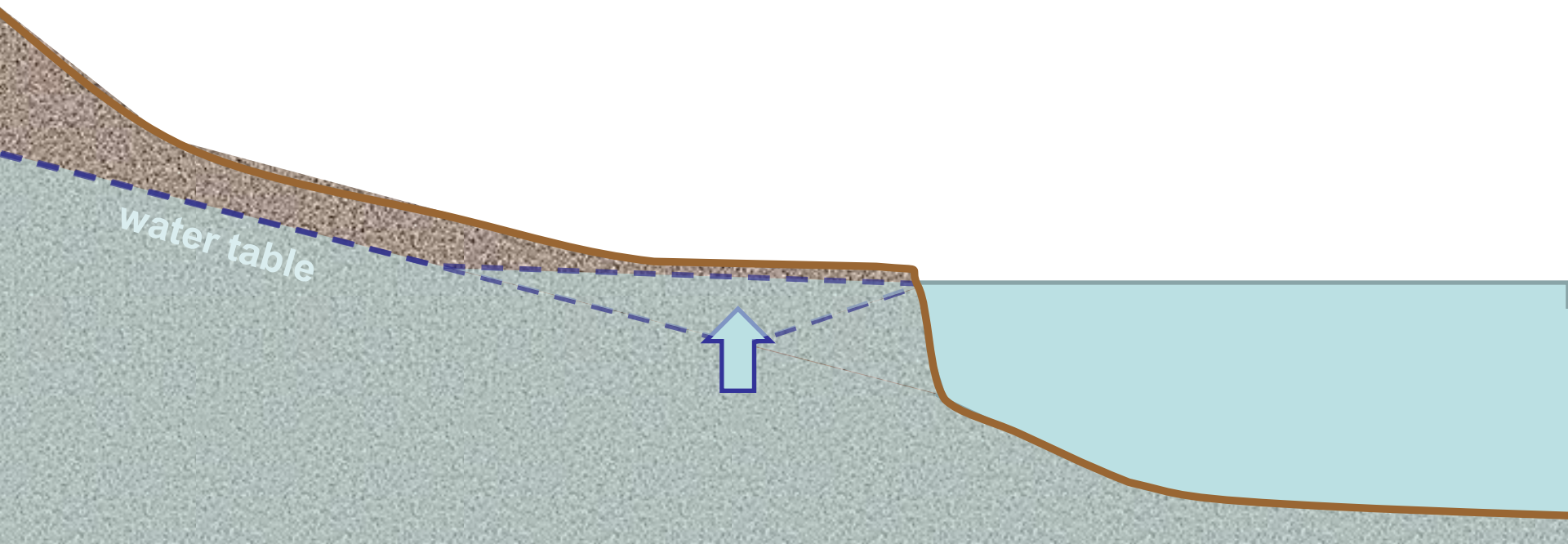
2.3 Groundwater / Surface Water Interactions – Local Groundwater Flow and Bank Recharge

- Bank recharge occurs when water levels in a surface water body (such as a lake) rise quickly such that the lake level is HIGHER than the groundwater level.
- This causes water to “reverse” and flow from the lake back into the shallow groundwater.
  - This in-turn causes local, shallow groundwater levels to rise.



2.3 Groundwater / Surface Water Interactions – Local Groundwater Flow and Bank Recharge

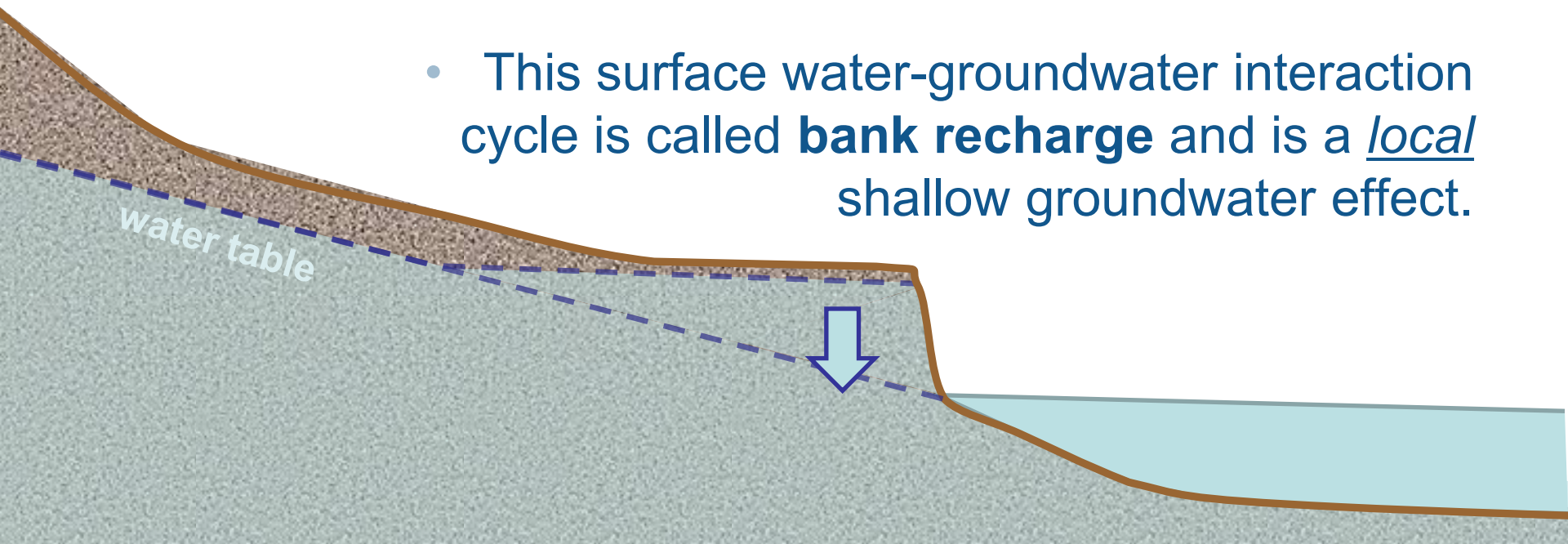
- Groundwater levels continue to rise…
- …until the lake levels start to drop.
- Groundwater levels then decline, but **lag** behind the lake level decline.

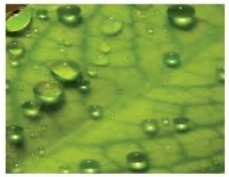


2.3 Groundwater / Surface Water Interactions – Local Groundwater Flow and Bank Recharge

- Groundwater levels continue to rise…
- …until the lake levels start to drop.
- Groundwater levels then decline, but **lag** behind the lake level decline.

- This surface water-groundwater interaction cycle is called **bank recharge** and is a *local* shallow groundwater effect.



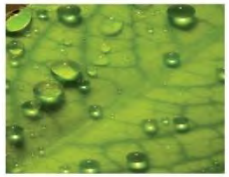
2.3 Groundwater / Surface Water Interactions – Local Groundwater Flow and Bank Recharge

- The rate and extent of bank recharge effects will be controlled by:
  - The permeability of the soil: sandy soils will feel the effect quicker.
  - The height of the lake level change.
  - And the duration that the lake is at a higher level. A short duration of higher lake level may have limited effect on near-shore shallow groundwater levels.

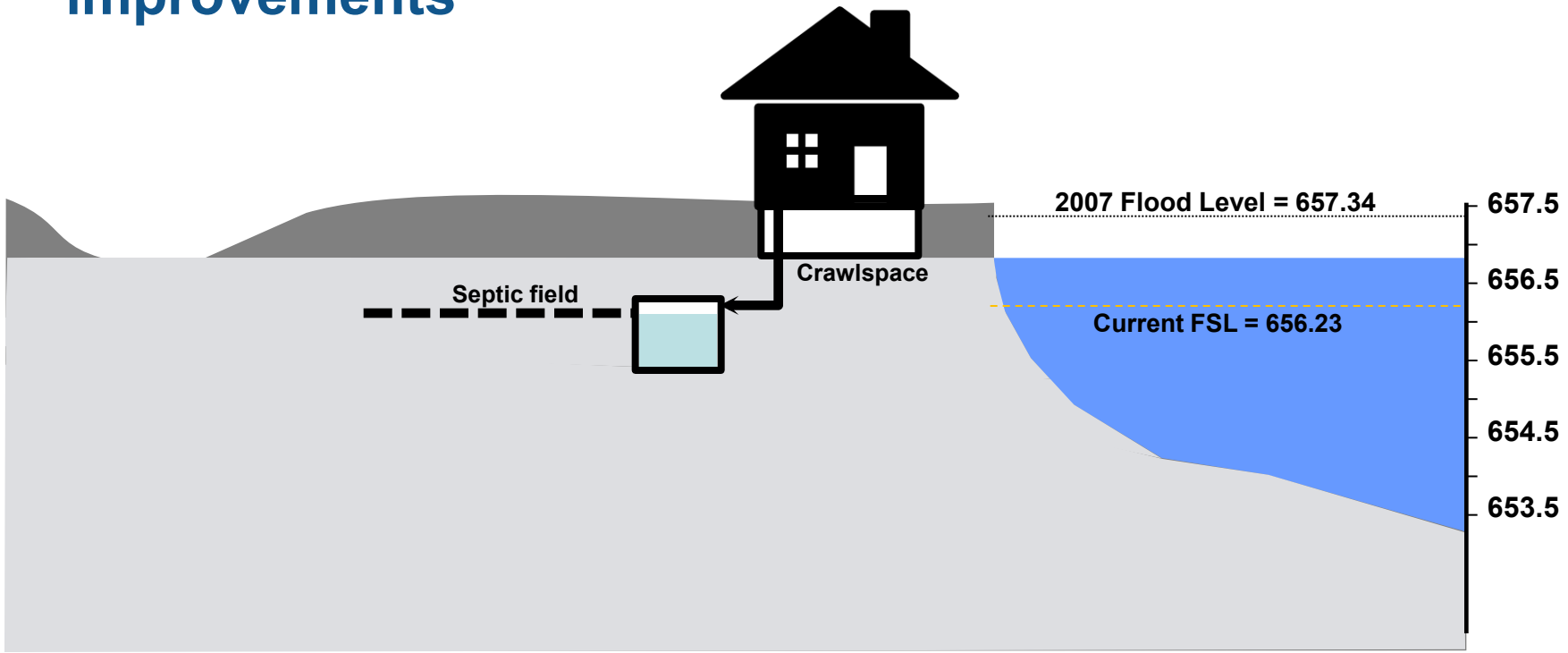
2.3 Groundwater / Surface Water Interactions – How does groundwater interact with private property improvements today?

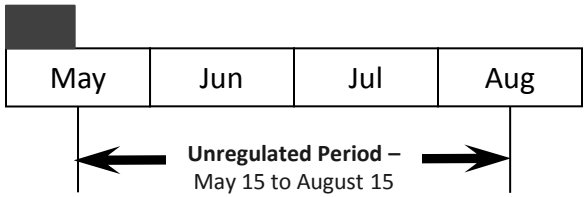
- Many properties have improvements below ground surface, including:
  - Septic fields
  - Basements
  - Crawlspaces,
  - Well pits, sumps, etc.
- Depending on elevations and ground conditions, groundwater can levels can rise above the elevation of these improvements.





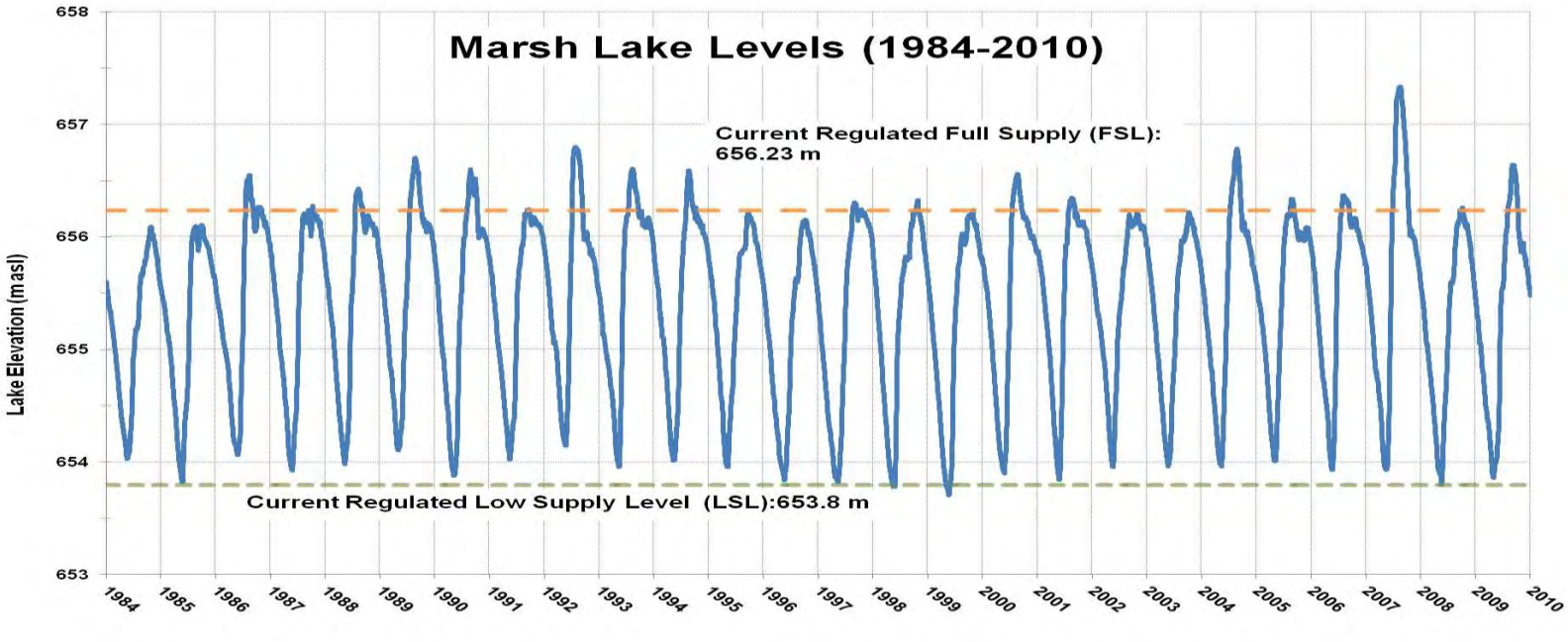

2.3 Groundwater / Surface Water Interactions – Illustration of groundwater interaction with property improvements





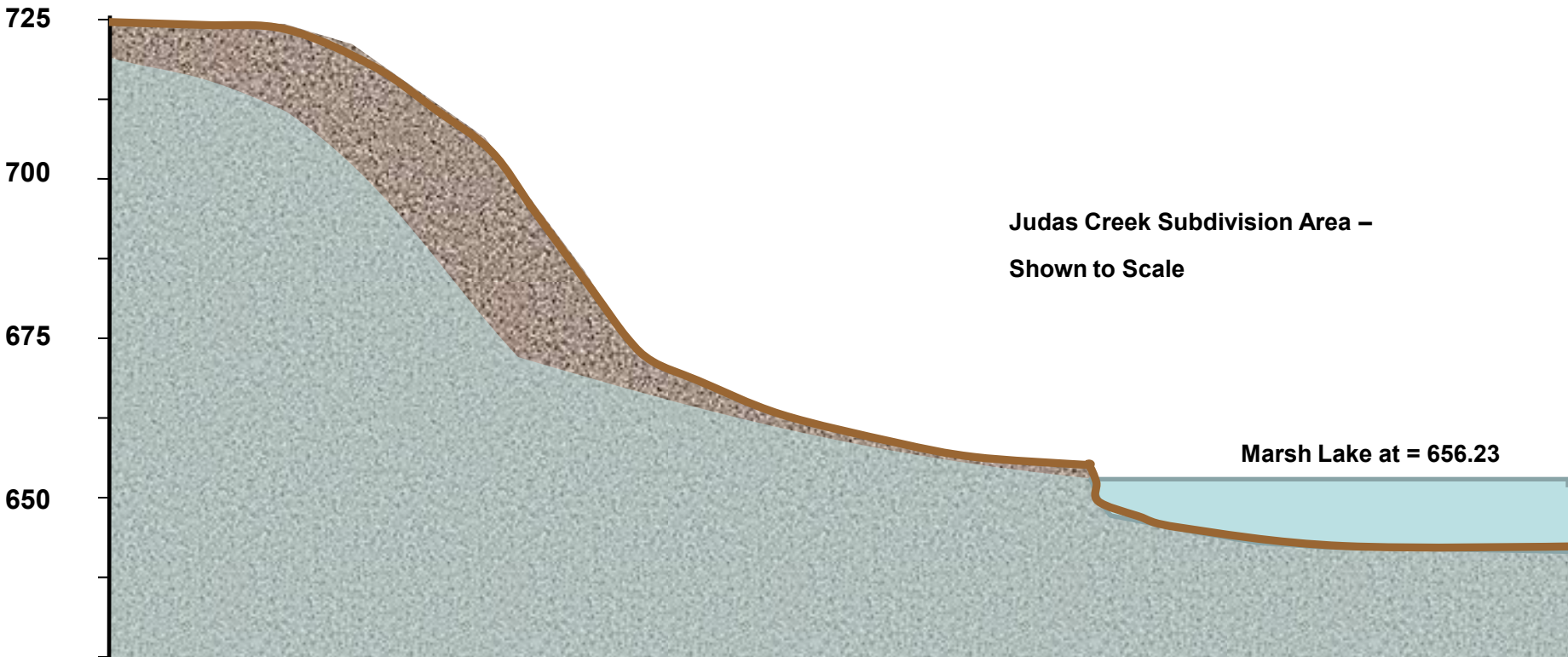
2.3 Groundwater / Surface Water Interactions – Current Conditions

Currently, many properties have either septic fields or crawlspaces located below current lake levels.



2.3 Groundwater / Surface Water Interactions – What is not effected

- Lake levels do not substantively effect groundwater levels on sloping sites



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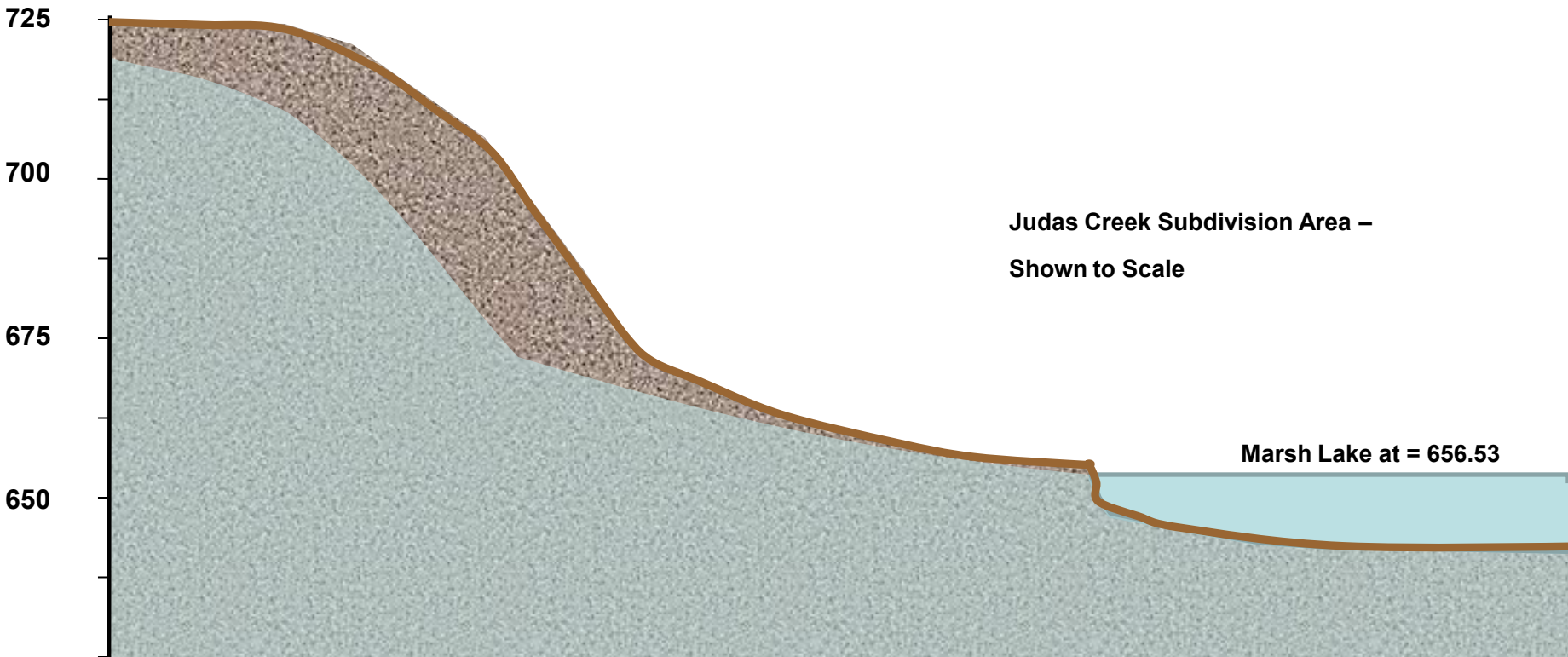
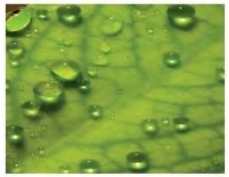
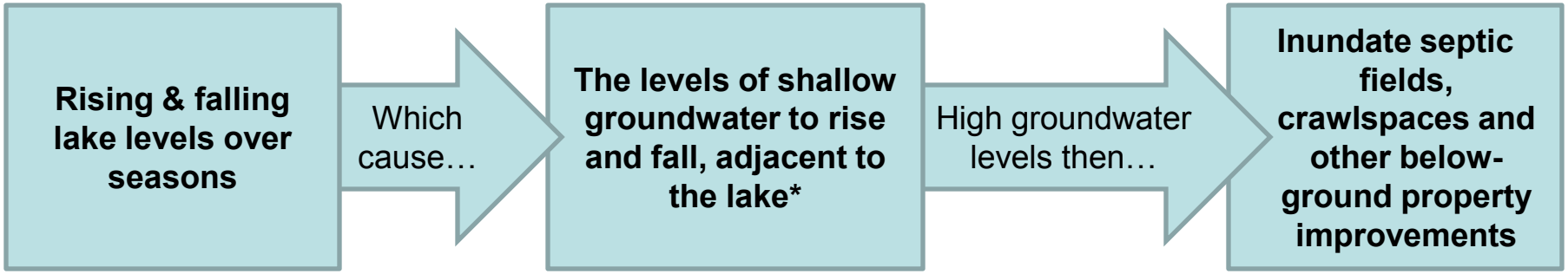


2.3 Groundwater / Surface Water Interactions – What is not effected

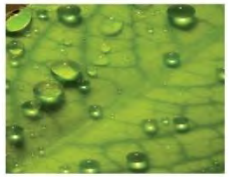
- Lake levels directly affect water levels in wetlands because most wetlands around the lake are directly connected to the lake. This is not a groundwater effect



2.3 Groundwater / Surface Water Interactions – Summary of how lake levels affect below-ground property improvements now



- *Remember:* lake level changes do not cause an immediate change to groundwater levels. Groundwater levels lag behind the surface water changes. The time delay varies depending on the soil type.
- Overall magnitude of groundwater fluctuation are not as great as surface water fluctuations.

Introduction to Groundwater Summary

1. Changes to water levels in Marsh Lake may effect shallow groundwater levels adjacent to the lake.

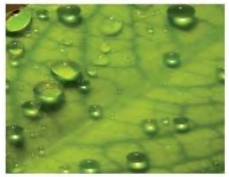
2. This is a very localized effect and is constrained to low-elevation areas immediately adjacent to the lake.

3. The *bank recharge* effect is much smaller than *regional groundwater flow* systems

Southern Lakes Enhanced Storage Workshop Series -

SCOPE OF THE GROUNDWATER INVESTIGATIONS

NOVEMBER 26, 2011

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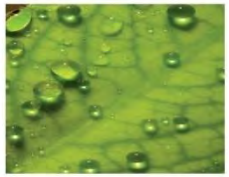
- **Preliminary Assessment of Effects to Shallow Groundwater**

  Concluding Discussion

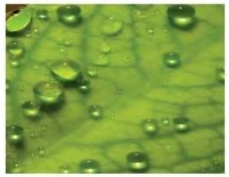
3.1 Purpose of the groundwater studies?

1. To understand where properties might be affected by changing groundwater levels associated with lake level changes.
   - Also to identify properties where the groundwater would *not* be affected by modified lake levels.

2. To understand the relationship between lake levels and shallow groundwater levels.
   - both in terms of water elevations and the timing of water level changes & duration.

3. To identify the elevations of improvements that might be affected by higher groundwater levels.
   - Basements, crawl spaces, septic fields, sump pumps, etc.

4. To understand current conditions – what is currently being affected under existing conditions.

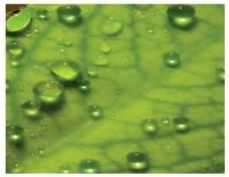



3.1 Areas of interest for groundwater/surface water interaction

1. Residential areas at low-elevation, which include:
   - Army beach (primarily the southern half)
   - South M'Clintock
   - Some properties at Old Constabulary
   - Tagish Bridge, including Tagish Creek, area

2. Additional areas investigated include:
   - Some properties at Judas Creek
   - Tagish Estates
   - California Beach

3. Areas not of concern:
   - Higher elevation properties (i.e. N. M'Clintock, Judas Creek, Mitchie Place, etc.)
   - Properties with improvements that are farther from the lakeshore.
   - Properties that do not have below-ground improvements.



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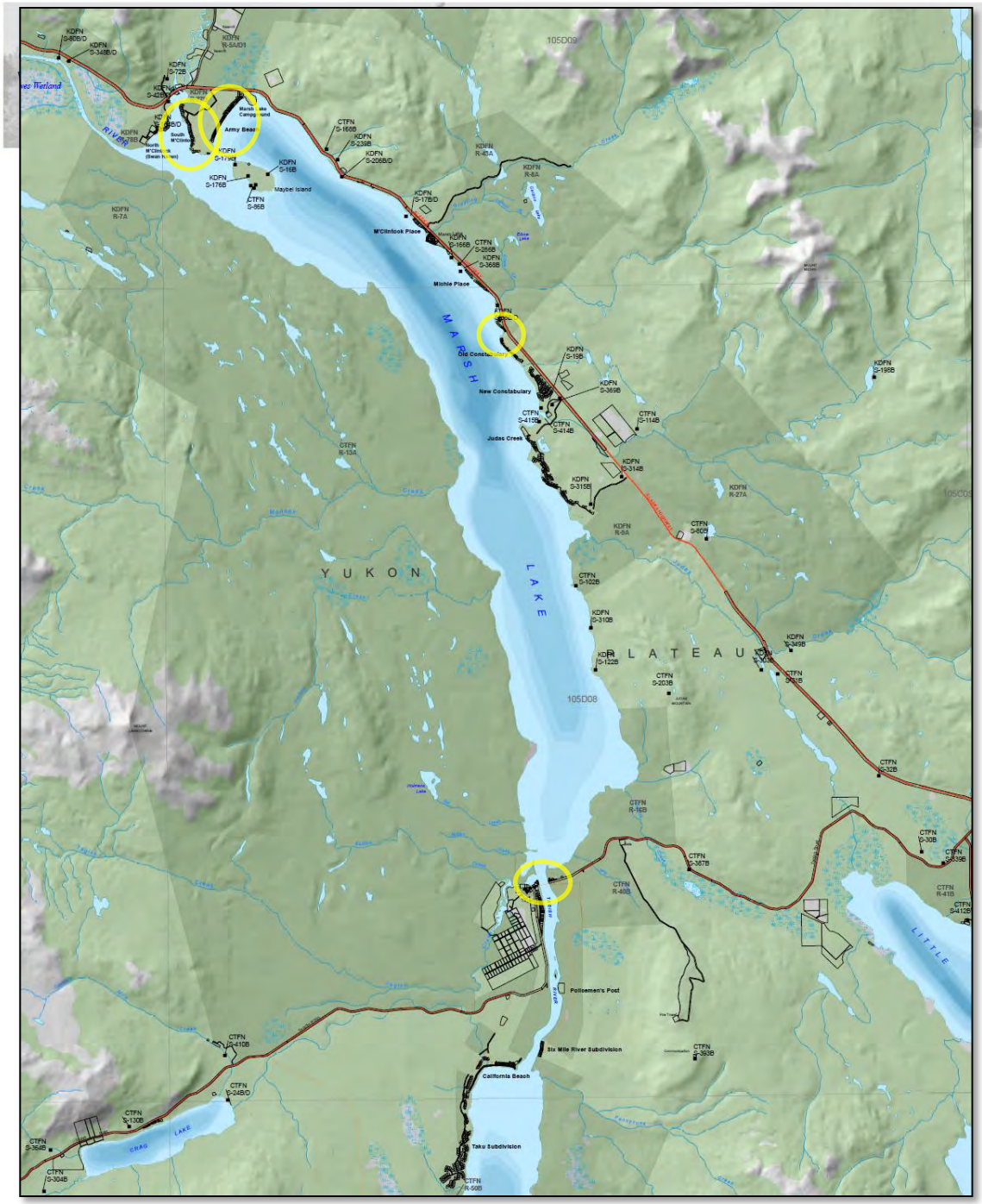
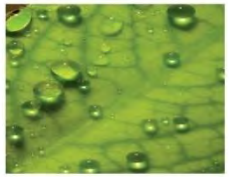






3.2 Groundwater Monitoring

- To understand how shallow groundwater behaves now, a series of shallow groundwater monitoring wells were installed in 2009 and 2010 at locations with low-elevation properties.

- In many locations, wells were installed as a “transect” to measure groundwater trends at various distances from the lake.

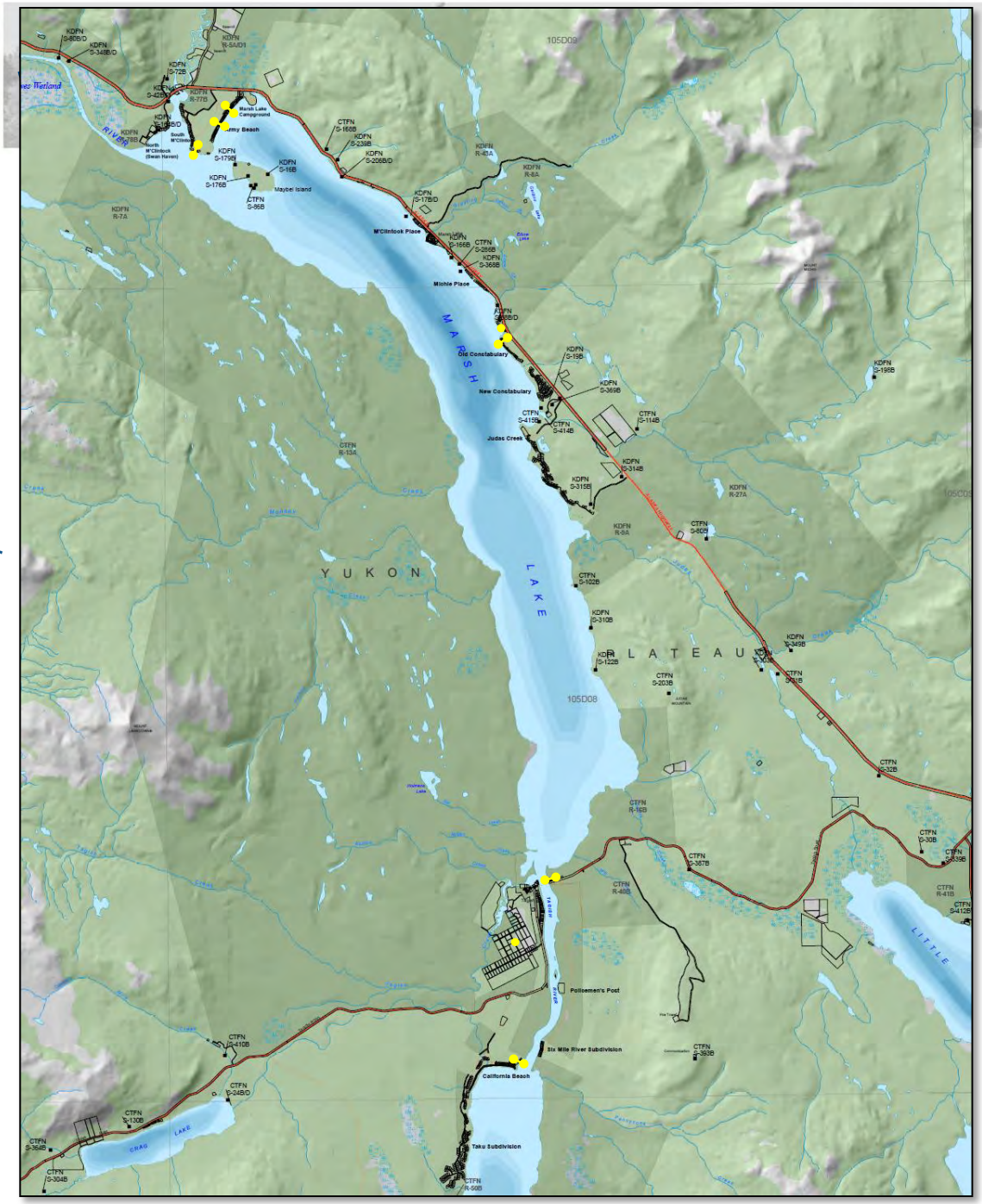
- Locations include:

➢ Installed in 2009:

1. Army Beach north transect (3 wells)
2. Army Beach middle transect (3 wells)
3. South M’Clintock transect (3 wells)

➢ Installed in 2010:

1. Old Constabulary transect (4 wells + 1 additional well)
2. Tagish Bridge transect (3 wells)
3. Tagish Estates, installed in 2010 (1 well)
4. California Beach (2 wells)

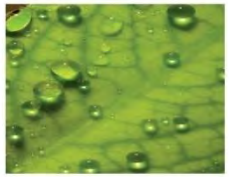


3.2 Monitoring wells

- Groundwater levels are measured with by installing a monitoring well (mini-piezometer).
- These are driven to 3 to 4 metres depth.
- Wells are surveyed to determine exact elevation, in metres above sea level. This allows comparison with lake levels, that are also recorded as elevation, above sea level (asl).

Mini-piezometer – protective casing open and water level being measured


Drive point tip at bottom of mini-piezometer

Scope of the Investigations

AECOM

3.2 Monitoring wells

- Water level dataloggers are installed in several wells which continuously record water levels and temperature.
- Dataloggers are downloaded monthly and depth-to-water is measured manually.

Downloading datalogger from monitoring well


Surveying of well elevations with Differential GPS

3.2 Groundwater Monitoring Results – Army Beach / South M'Clintock

- 3 transects with over 2 years of data



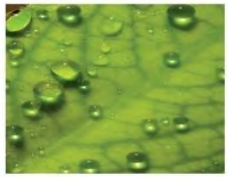
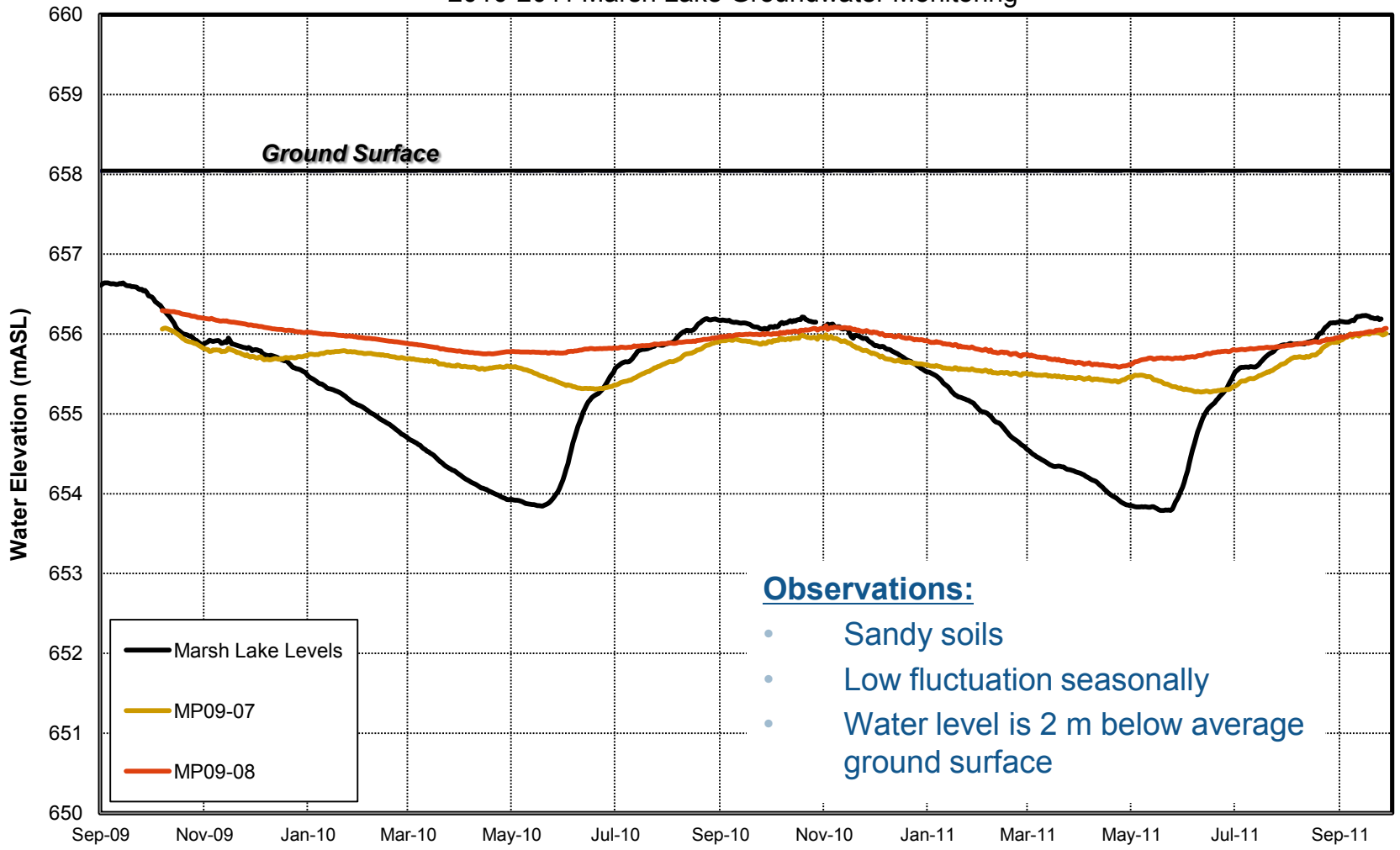



Figure 6. Army Beach - North Transect
2010-2011 Marsh Lake Groundwater Monitoring



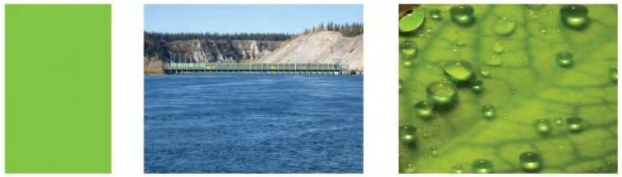
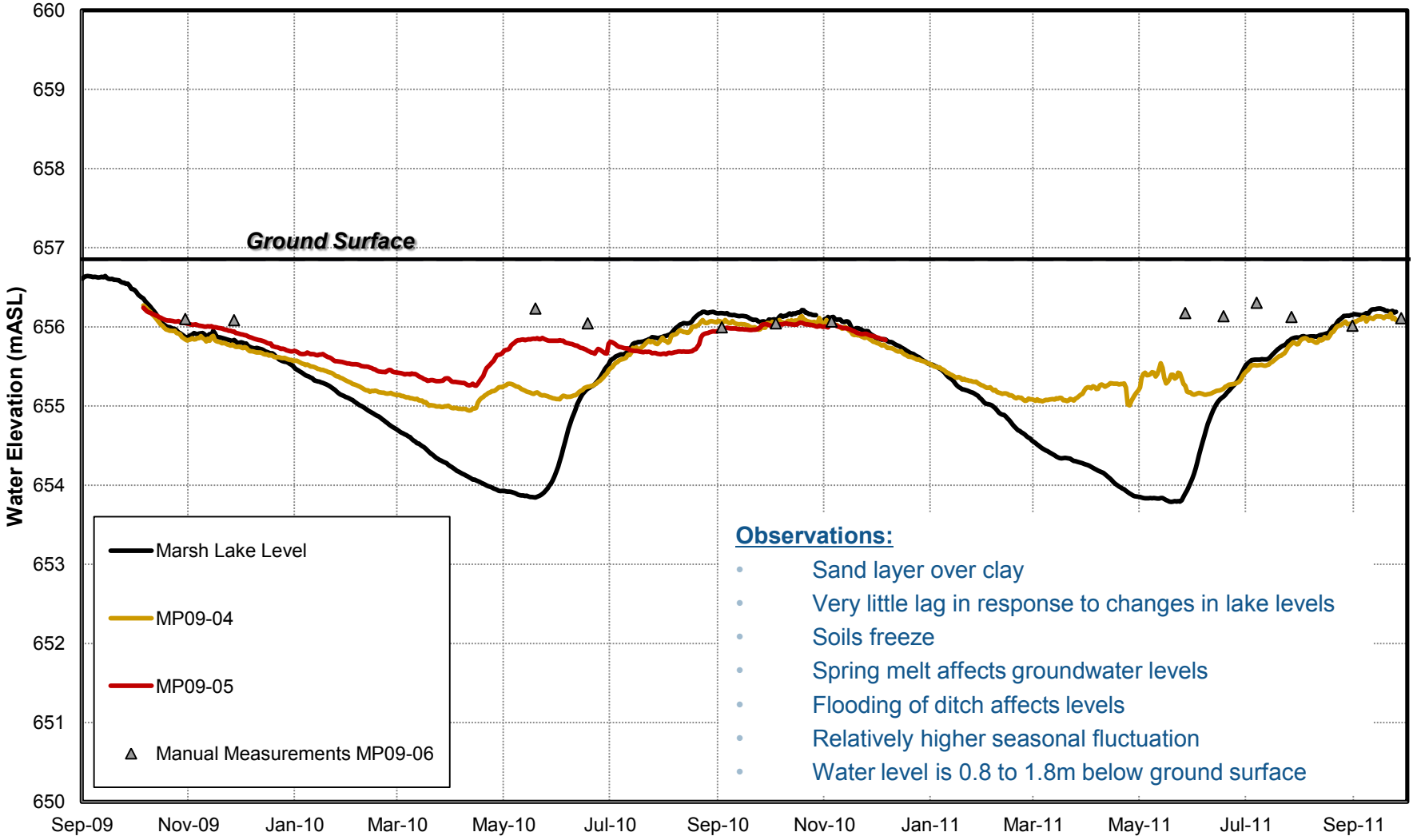


Figure 5. Army Beach - Middle Transect

2010-2011 Marsh Lake Groundwater Monitoring



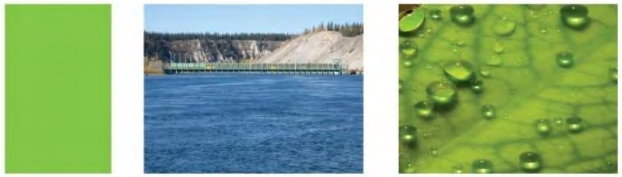


Figure 4. South M'Clintock- South Transect
2010-2011 Marsh Lake Groundwater Monitoring

Water Elevation (mASL)

660
659
658
657
656
655
654
653
652
651
650

Ground Surface

Marsh Lake Levels
MP09-01
MP09-02

Sep-09 Nov-09 Jan-10 Mar-10 May-10 Jul-10 Sep-10 Nov-10 Jan-11 Mar-11 May-11 Jul-11 Sep-11

Observations:

- Finer grained soils
- Groundwater levels lag behind the change in lake level ~ 1 to 2 months
- Spring melt affects groundwater levels substantively
- Relatively higher seasonal fluctuation
- Water level is 0.7 to 1.9m below ground surface

3.2 Groundwater Monitoring Results – Old Constabulary

- one transect of four wells with over a year of data

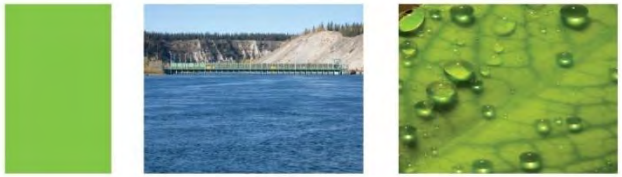
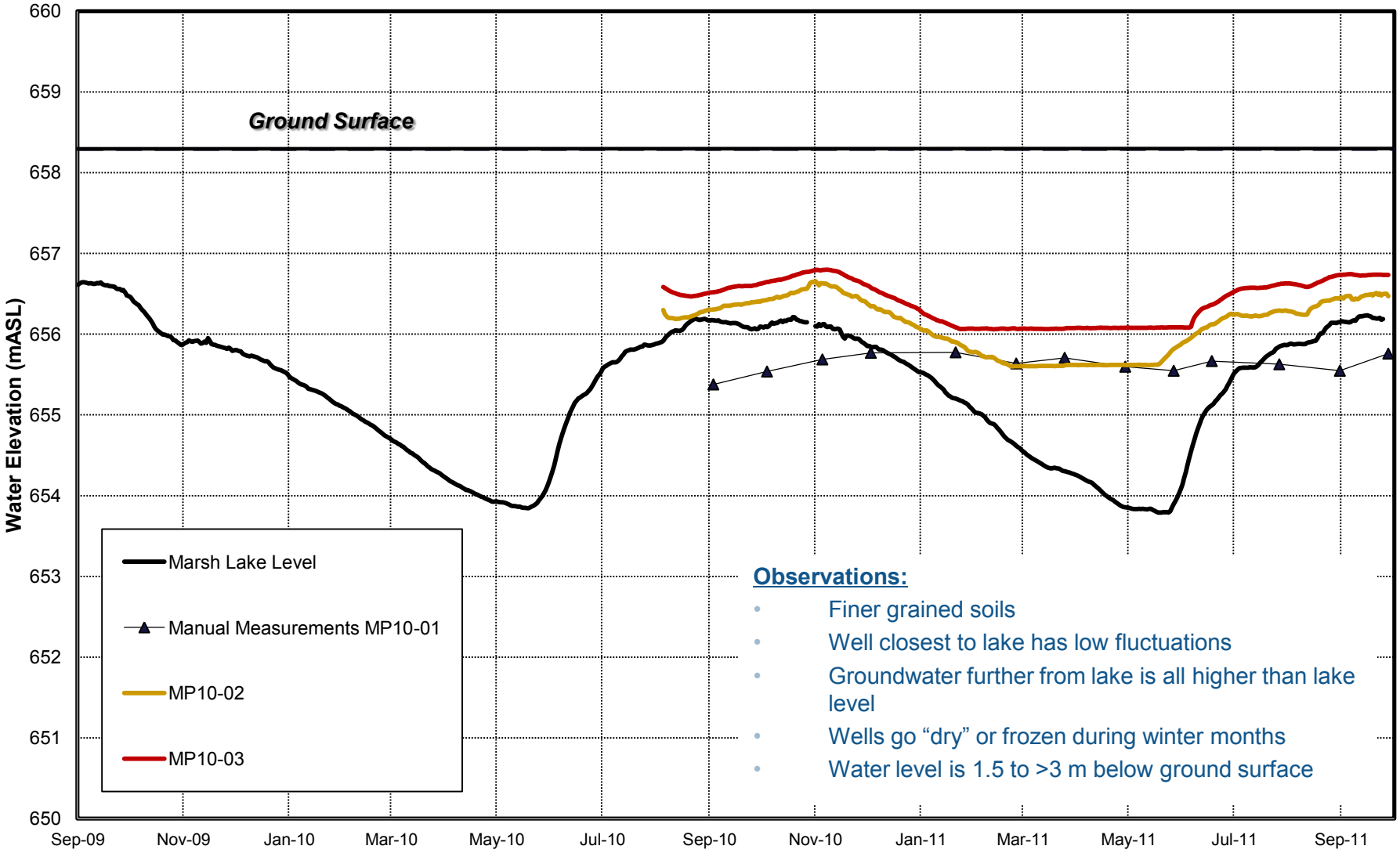
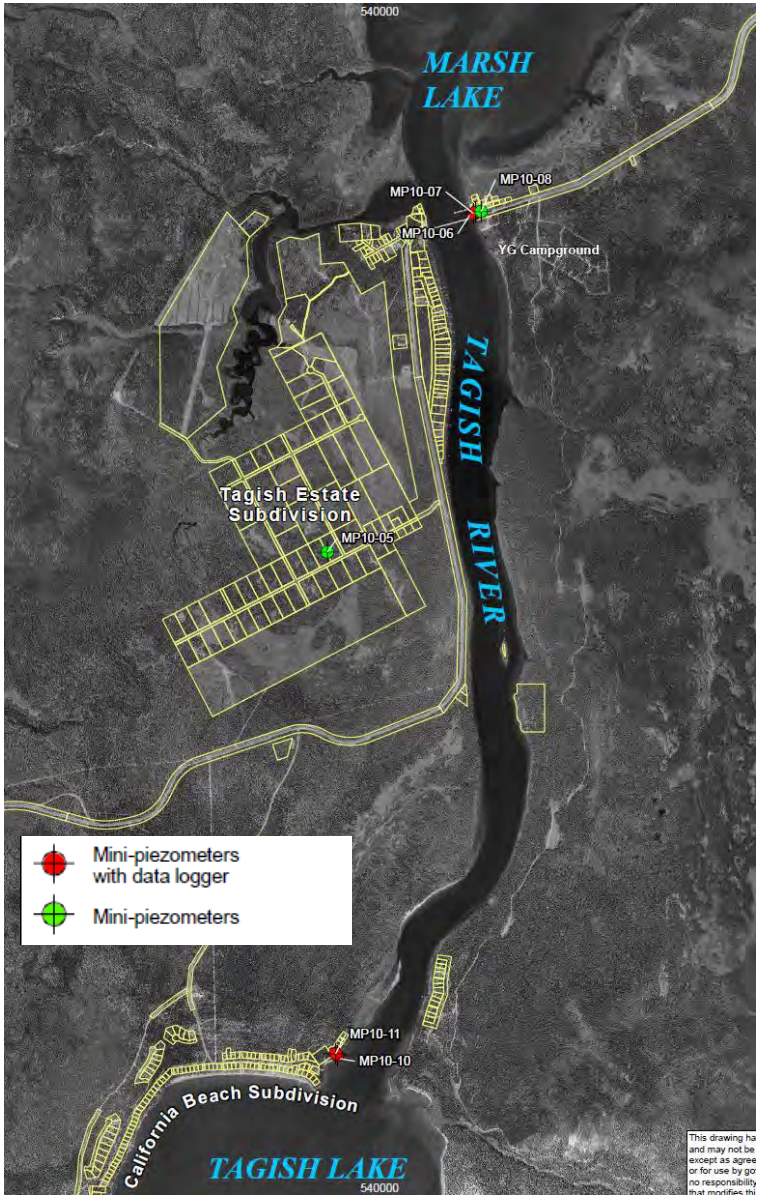


Figure 7. Old Constabulary Subdivision
2010-2011 Marsh Lake Groundwater Monitoring



3.2 Groundwater Monitoring Results – Tagish

- Two transects, one at Tagish Bridge, one at California Beach. Each transect with more than one year of data
- Monitor well at Tagish Estates is 3.6 m deep and dry. Some water found in well after rain events. It has been monitored for more than a year.
  - Therefore, issues at Tagish Estates are drainage related (i.e. fine grained soils) and not groundwater.



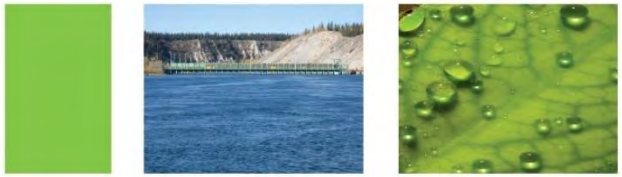
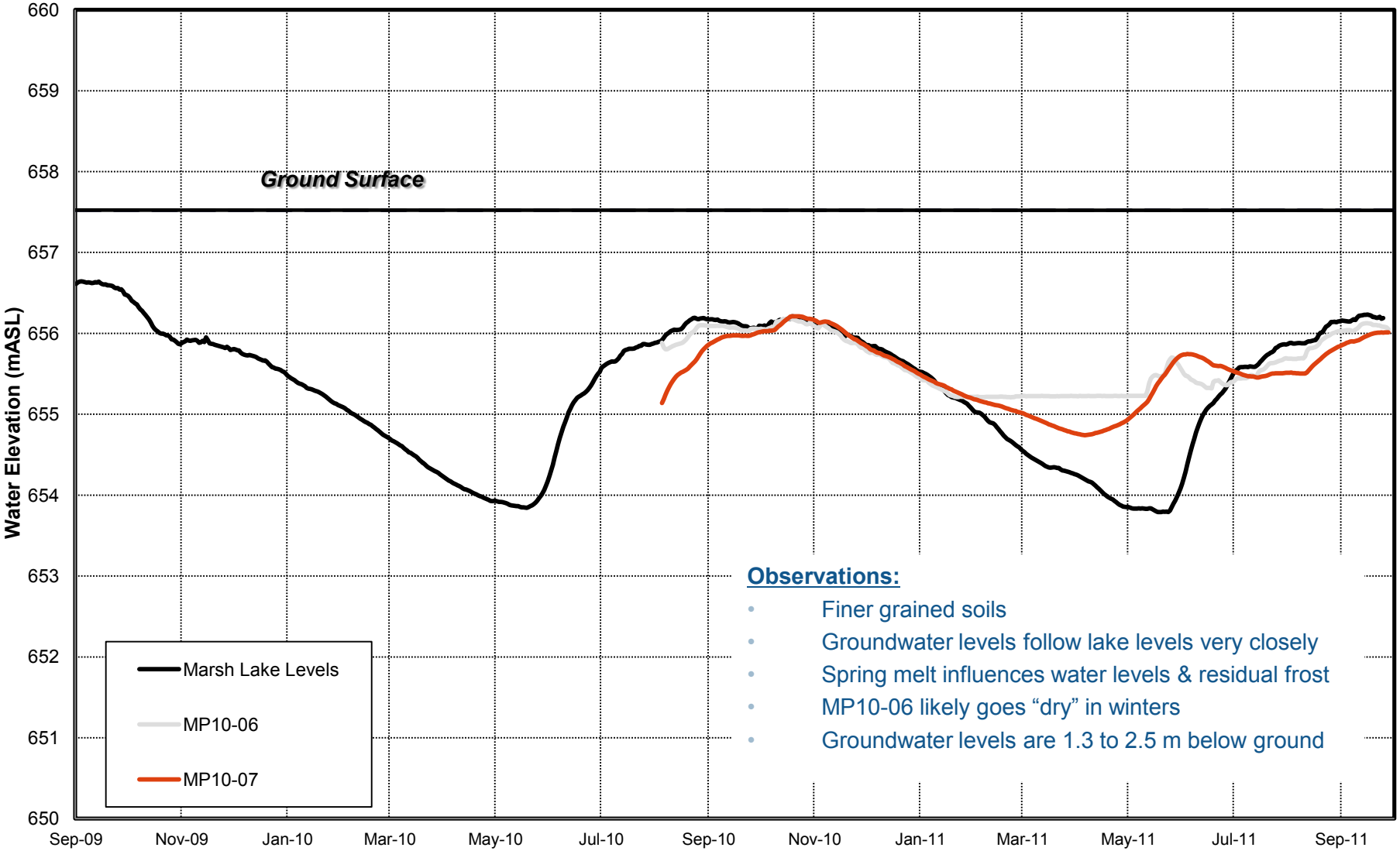


Figure 8. Tagish Bridge

2010-2011 Marsh Lake Groundwater Monitoring



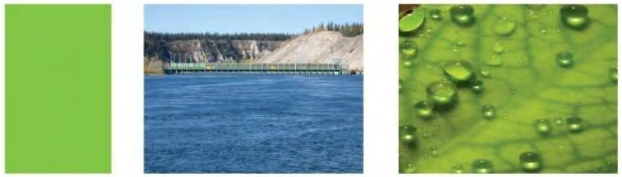
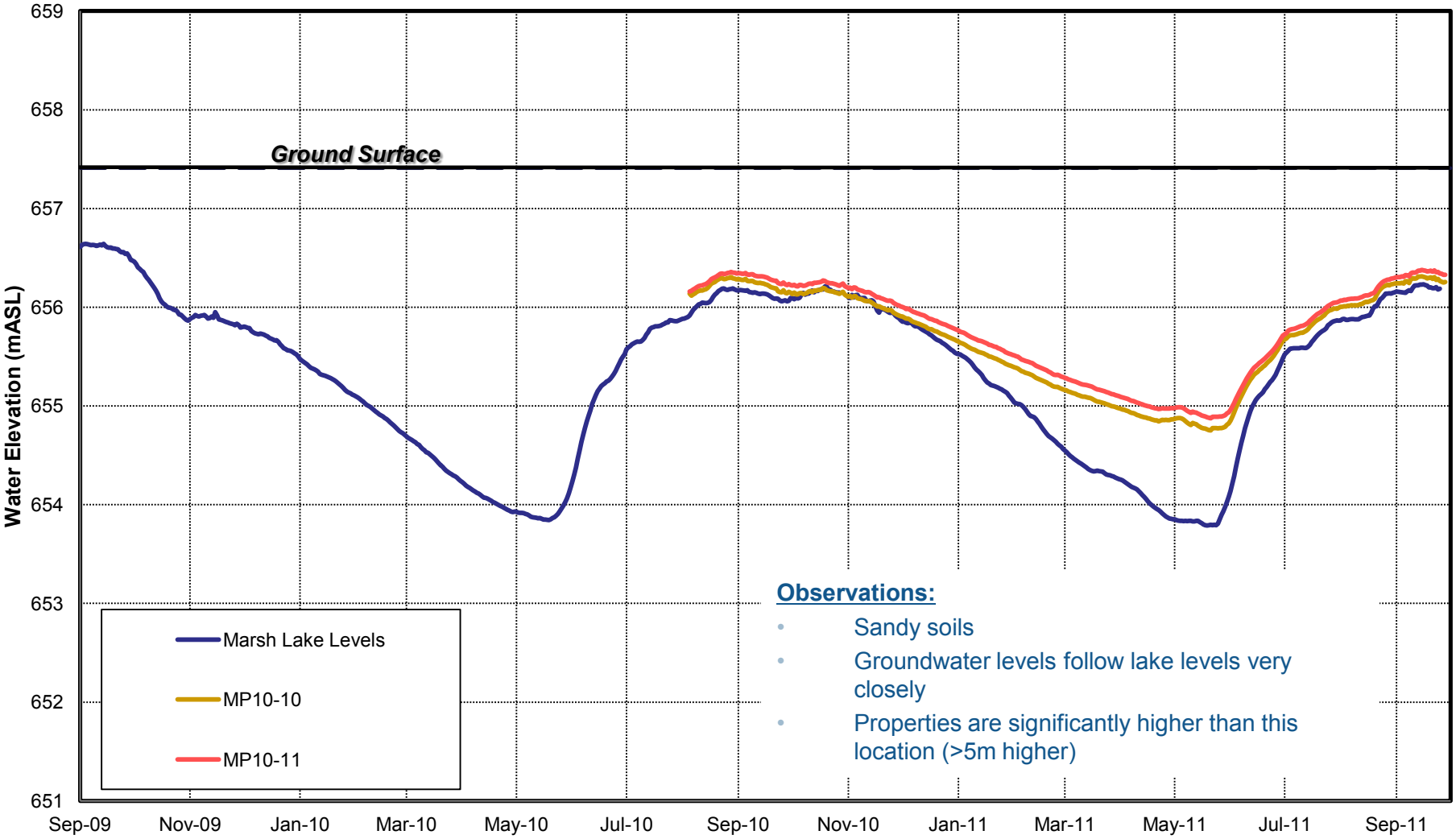


Figure 9. California Beach Subdivision
2010-2011 Marsh Lake Groundwater Monitoring



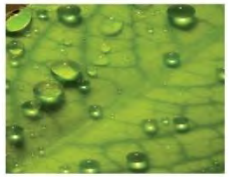
3.3 Property Improvement Surveys

Purpose:

- To inventory the type(s) of below-ground property improvements, their relative depth and distance from the lake, at the areas of interest.
- Typically below ground improvements include:
  - Basements
  - Crawl spaces
  - Septic fields
  - Other

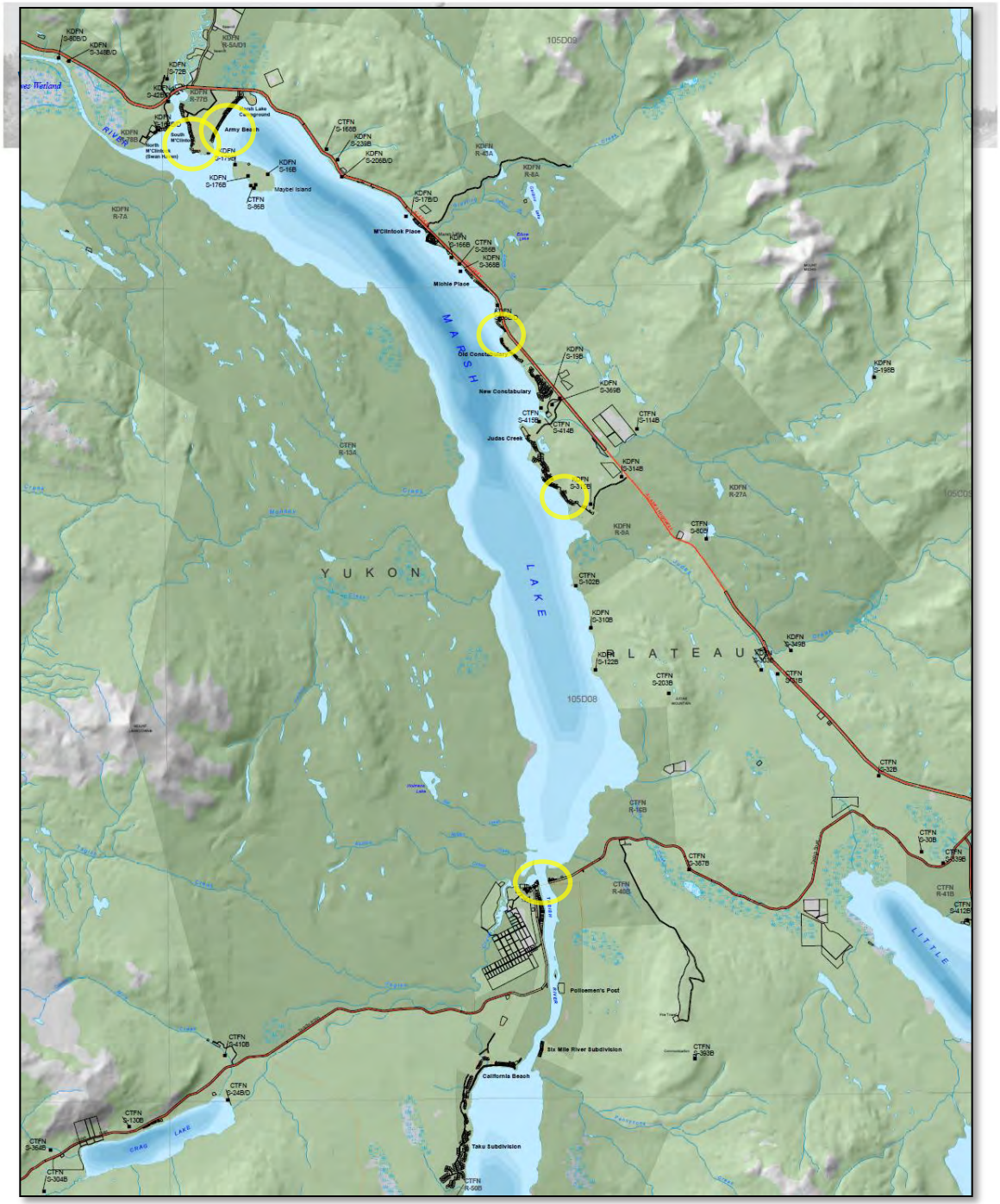
Methodology:

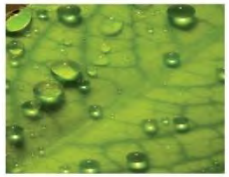
1. Visual survey to identify areas of concern
2. Telephone survey and interviews
3. Follow-up site visits to conduct elevation surveys of a representative sample



3.3 Areas of property improvement surveys

1. 61 property owners contacted for interviews
2. Follow-up elevation survey at:
   - 9 in Army Beach
   - 8 in South M'Clintock
   - 4 in Old Constabulary
   - 2 properties in Judas Creek
   - 5 properties at Tagish Bridge (2 not surveyed)



Scope of the Investigations

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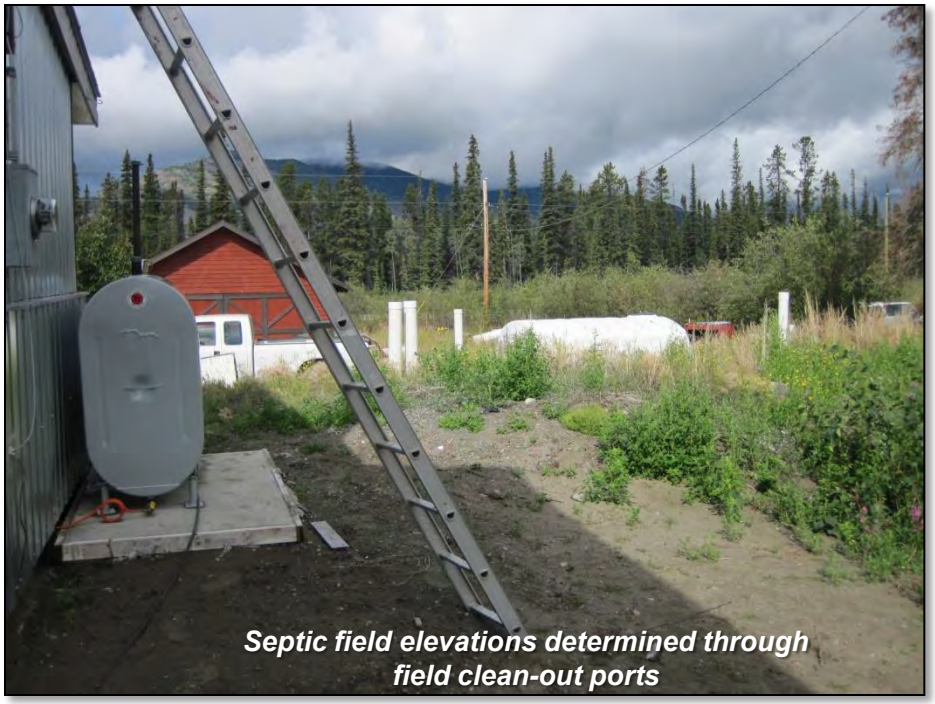
3.3 Property improvement surveys

- Interviews with owners to identify types of below ground property improvement and any problems related to groundwater to date.

- Elevation survey of septic fields, crawl spaces and sump pumps.



Septic field elevations determined through field clean-out ports

Surveying of crawl space elevations

Scope of the Investigations

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3.3 Property improvement surveys

Properties surveyed in South M'Clintock & Army Beach area

Scope of the Investigations

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3.3 Property improvement surveys

Properties surveyed in Old Constabulary area

Scope of the Investigations

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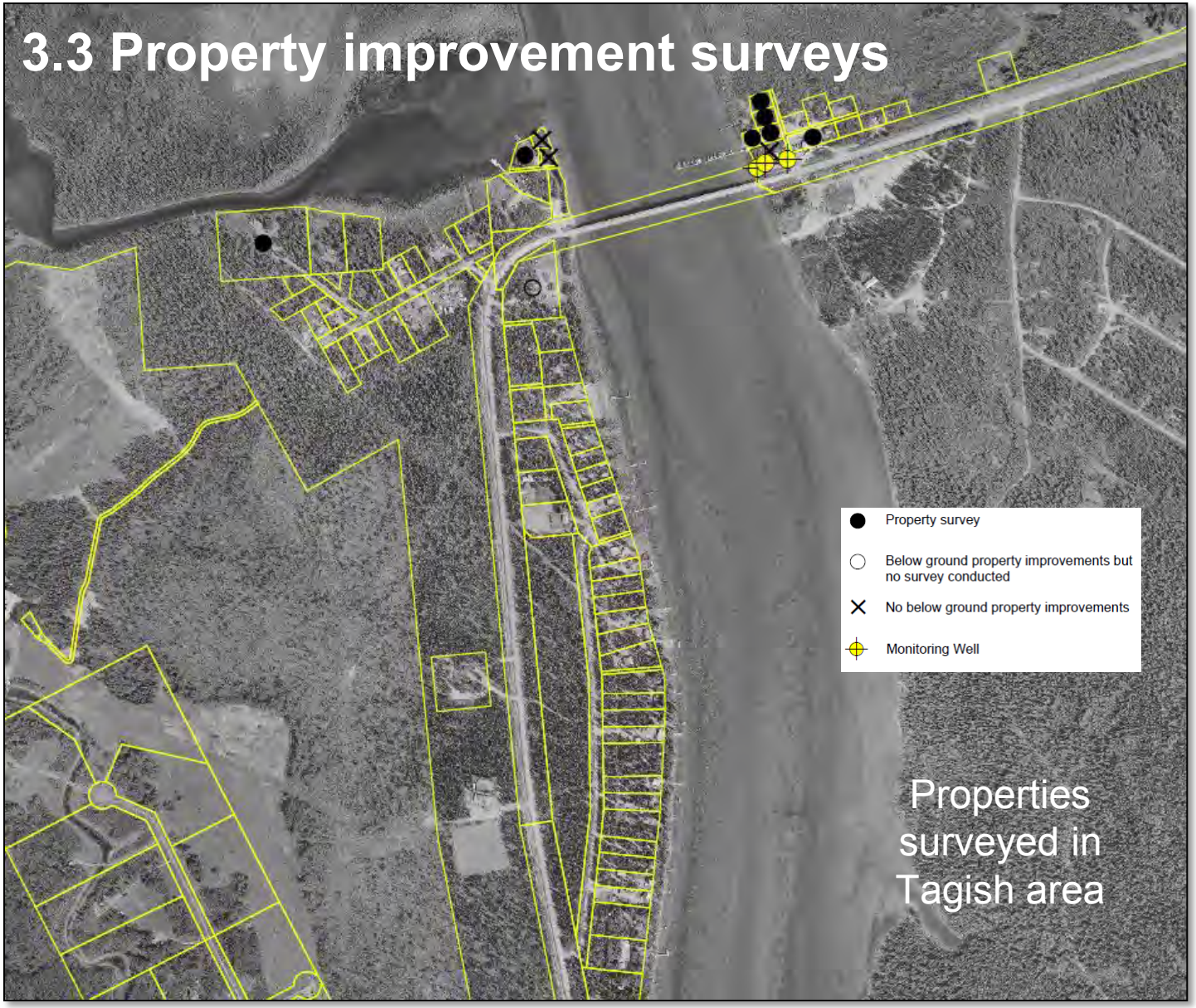
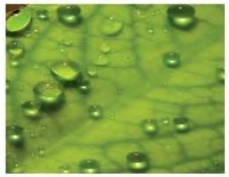
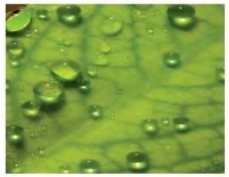
3.3 Property improvement surveys



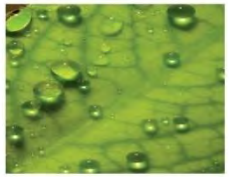
3.3 Property improvement surveys general findings

- Most septic fields surveyed are below current average lake levels (i.e. 656.23m ASL) and therefore are likely inundated regularly.
  - Note that current regulations require septic fields to be 1.2 m above “seasonal high water”
- Very few people reported problems with their septic fields, other than 2007.
- Several homes have sump pumps, some of which currently run much of the summer and fall.

3.3 Property improvement surveys results

	Army Beach	South M'Clintock	Old Constabulary	Tagish Bridge
Number of properties surveyed in area	9	8	4	3
Septic fields below elevation 656.53	5	6	2	2
Crawl spaces or other improvements below elevation 656.53	3	1	1	1

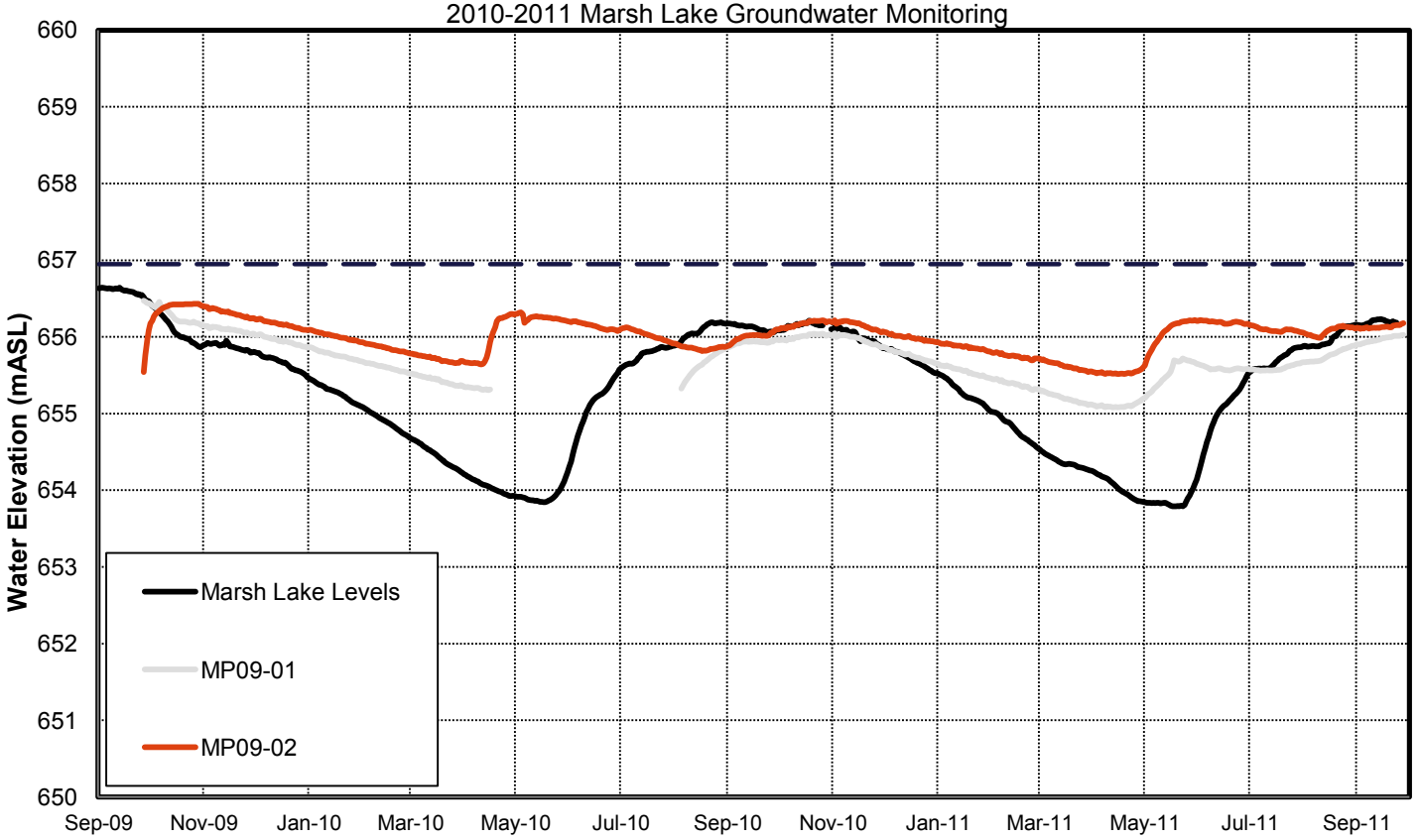



Groundwater Studies Summary

- 20 groundwater monitoring wells installed at 7 locations around Marsh Lake and Tagish.
- One to two years of groundwater level data collected from the monitoring wells.
- Property surveys conducted to identify type, location and elevation of shallow, below-ground property improvements.
- Many existing below-ground improvements are deeper than current lake levels (e.g. 656.23 m ASL), however few owners reported problems.

Discussion

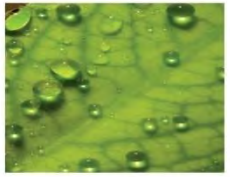
Figure 4. South M'Clintock- South Transect
2010-2011 Marsh Lake Groundwater Monitoring



Southern Lakes Enhanced Storage Workshop Series -

PRELIMINARY ASSESSMENT OF EFFECTS TO GROUNDWATER

NOVEMBER 26, 2011

Groundwater Workshop Outline

- **Overview of the Project Concept**

  Discussion & questions

- **Introduction to Groundwater**
  1. Why are we talking about groundwater?
  2. Groundwater fundamentals
  3. Surface water/groundwater interaction

  Discussion break

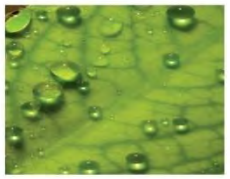
- **Scope of the Investigations**
  1. Purpose
  2. Groundwater monitoring
  3. Property surveys

  Discussion break

- **Preliminary Assessment of Effects to Shallow Groundwater**

  Concluding Discussion

We are here

4.1 Preliminary Assessment of the Effects to Groundwater?

1. Hypothesis
   - What is the linkage between lake levels and groundwater?
   - What areas not affected by changed lake levels?

2. How can the proposed changed be assessed?
   - Groundwater model development
   - Model calibration & verification of results

3. Preliminary Findings

4.1 Groundwater Effects Hypothesis

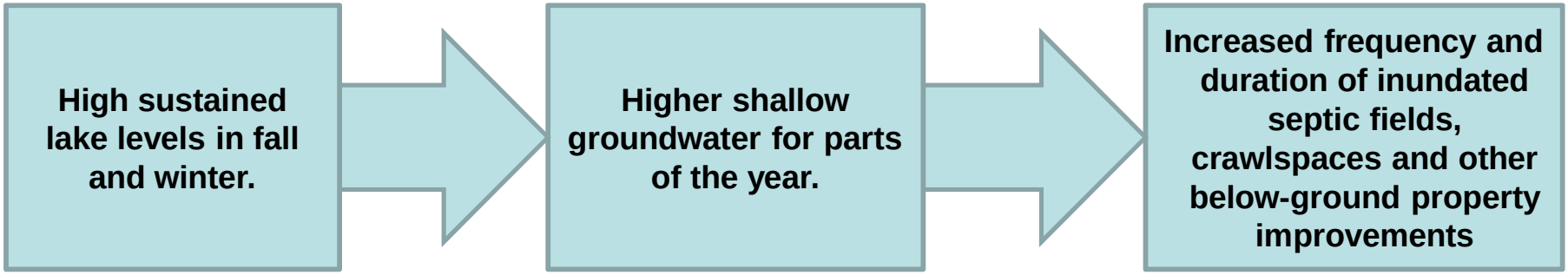
- To assess proposed project effects on groundwater, a hypothesis is developed and tested:

Hypothesis:

- *Sustained higher lake levels will result in sustained higher groundwater levels.*
- *Higher groundwater levels will negatively affect below-ground improvements.*

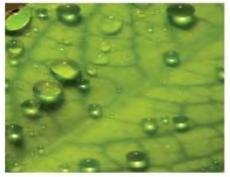
4.1 Pathway of the Effect

- To assess proposed project effects on property improvements, the effects pathway is as follows:



4.1 Areas where changes to groundwater will NOT affect improvements

- Many areas around Marsh and Tagish Lake are not affected by higher sustained groundwater levels.
  - Higher elevation improvements, such as at N. M'clintock, Michie Place, California Beach, etc.
  - Rising hillsides where below-ground improvements are above lake levels, for example Judas Creek).
  - Areas where groundwater is not influenced due to soil type (clay or silty soils) and/or distance from the lakes, for example Tagish Estates.

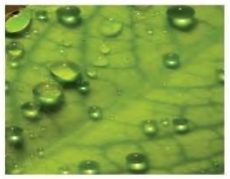



4.2 How can the proposed change to shallow groundwater levels be assessed?

1. Calculate the average number of days that improvements are saturated under *current conditions*.

2. Calculate the average number of days that improvements are predicted to be saturated *proposed conditions*.

3. Compare the *difference* in average number of days the below-ground improvements are saturated.
   - Does it change? Does it increase? Decrease? And by how much?



4.2 Groundwater flow model

1. A numerical groundwater flow model is developed to calculate groundwater levels.
2. The groundwater models are used to simulate groundwater levels and how the levels change over time and distance from the lake in response to varying lake levels throughout the years.
3. The groundwater models are calibrated to the actual, real-world water level data collected from the piezometer transects
4. The calibrated model can reproduce real-world conditions which gives us confidence in its predictive capability.
5. 50 years of lake level data are run through the model to generate the range, average and duration of groundwater levels.
6. The average number of days the the improvements are saturated are calculated for existing and proposed conditions.

Preliminary Assessment of Effects to Groundwater

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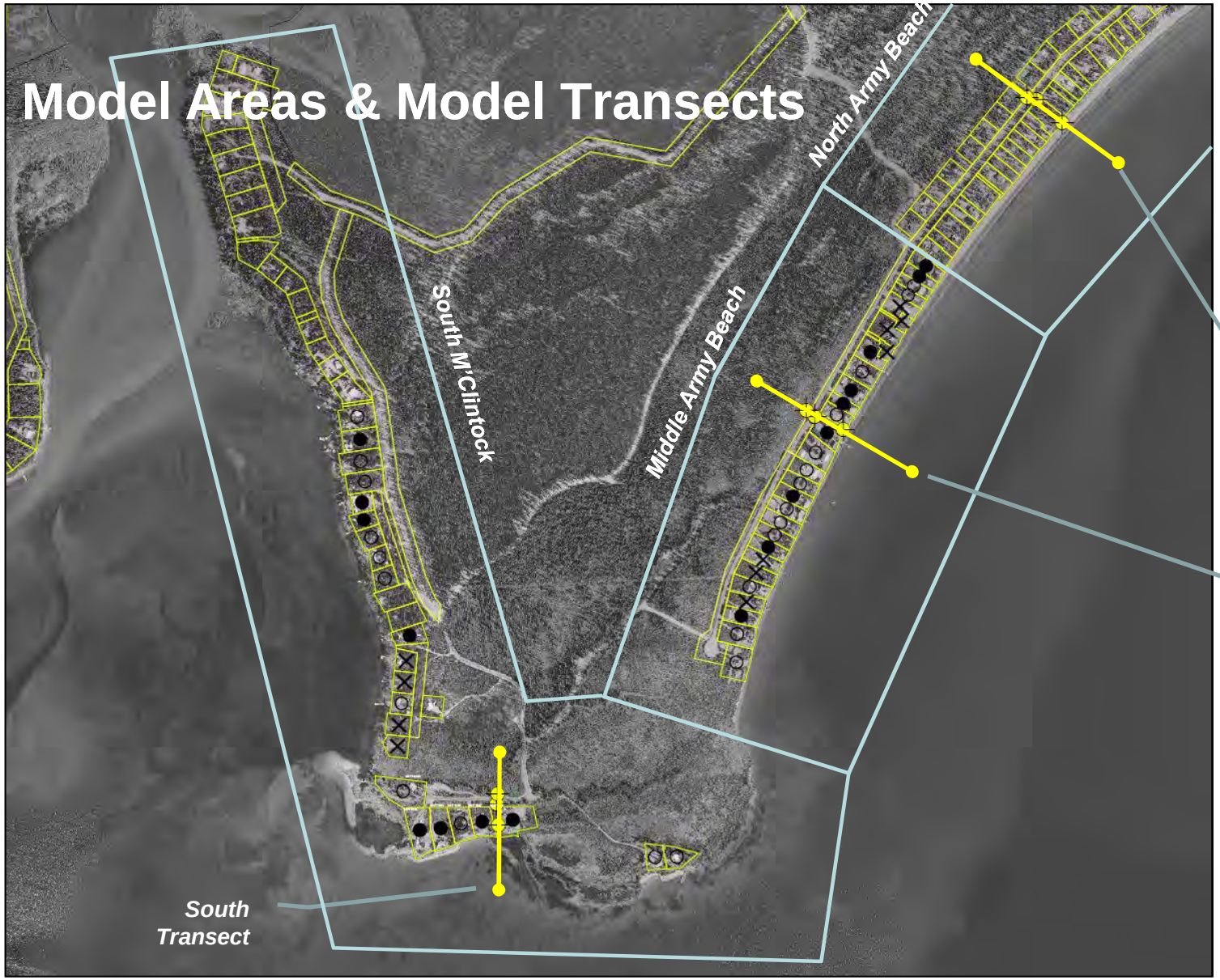
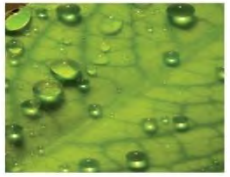


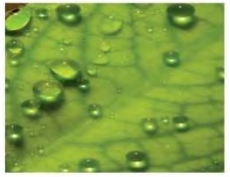


Preliminary Assessment of Effects to Groundwater

AECOM

Model Areas & Model Transects

Old Constabulary



Preliminary Assessment of Effects to Groundwater

AECOM

Model Areas & Model Transects

Tagish

4.2 Image of Model

1. Model theory? Background on the model?

4.2 Calibration results

1. Middle transect

4.2 Calibration results

1. South transect

4.2 Calibration results

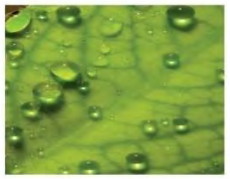
1. Conclusion statement – we can reproduce reality!

4.3 Preliminary Modelling Results

Preliminary results and subject to change.

1. Initial modeling results – so far only Army Beach Middle Transect and South M'Clintock Transects model runs.

2. Results are for:
   - Existing conditions
   - Initial project concept
   - A representative sample of improvements have been modeled to date.



4.3 Preliminary Results – Army Beach – Middle Transect

Sample improvements

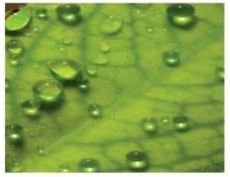
Sample Property Improvement Elevation (m ASL)	Type of Improvement	Average Distance from Lake (m)	Current Average # of Days Inundated	Project Scenario Average # of Days Inundated	Change (Ave. # of days / year)
656.59	Septic Field	41	**9**	15	6
656.35	Crawl Space	15	**24**	140	117
656.10	Septic Field	34	**79**	173	93
655.90	Sump pump	18	**140**	194	54

The magnitude of the water level change is variable for each property, and that assessment work still underway.

Reference Elevations:

- High lake average elevation (25% of years): 656.6 m ASL
- Proposed new Full Supply Level: 656.53
- Current average peak lake elevation: 656.29 m ASL
- Current Full Supply Level: 656.23

4.3 Example magnitude plot



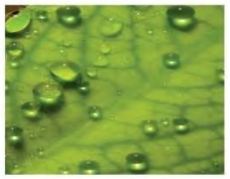
4.3 Preliminary Results – S. M'Clintock

Example property improvements

Example Property Improvement Elevation (m ASL)	Type of Improvement	Average Distance from Lake (m)	Current Average # of Days Inundated	Project Scenario Average # of Days Inundated	Change (Ave. # of days / year)

Reference Elevations:

- High lake average elevation (25% of years): 656.6 m ASL
- Proposed new Full Supply Level: 656.53
- Current average peak lake elevation: 656.29 m ASL
- Current Full Supply Level: 656.23

Summary of Preliminary Results

- Some existing improvements are experiencing weeks to months of saturation; however the improvements appear to be functioning.

- Under the project concept, the duration of saturation will increase in some cases.

- Next steps:
  - Analysis is not complete and will need to be extended to all properties of interest.
  - Affects to individual properties will need to be determined on a site specific basis.