City of McCleary's Wildcat Creek Aquifer Sustainability Plan Project

Wildcat Creek Aquifer Sustainability Plan
City of McCleary, WA

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List of Abbreviations

ASP	Aquifer Sustainability Plan
bgs	Below Ground Surface
BMPs	Best Management Practices
City	City of McCleary
cfs	Cubic feet per second
ft	Feet
G-5	General Development five-acre
GIS	Geographical Information System
GMA	Growth Management Act
LID	Low Impact Development
mg/liter	Milligrams per liter
NDMI	Normalized Difference Moisture Index
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathways
RCW	Revised Code of Washington
RLD	Residential Low Impact
S	Storativity
SWIR	Short Wave Infrared
SWL	Static Water Level
T	Transmissivity
TCC	Thurston County Code
TDR	Transfer of Development Rights
USGS	United States Geological Survey
WAC	Washington Administrative Code

Executive Summary

In 2022, the city of McCleary (City) initiated the Aquifer Sustainability Plan (ASP) project in response to concerns over groundwater quality and quantity in the Wildcat Creek Aquifer (Figure 1) The aquifer is the City's only source of reliable drinking water and supports most other users in the basin. The Department of Ecology has closed Wildcat Creek between May 1 and October 31 by rule[1], meaning no water is available for appropriation from the creek and no unmitigated consumptive groundwater use should be approved that captures water from the creek during the closed period. To address long-term use and protection of the aquifer, McCleary developed the ASP project as a framework to achieve long-term reliability over a 20-year horizon.

The ASP project brings together a variety of stakeholders to design a conjunctive use strategy to manage groundwater and surface water in the basin. The first phase of the ASP project included updating our current knowledge of aquifer conditions, working with the community to understand concerns and issues related to water resources, and to propose water management considerations and project management actions to promote aquifer sustainability.

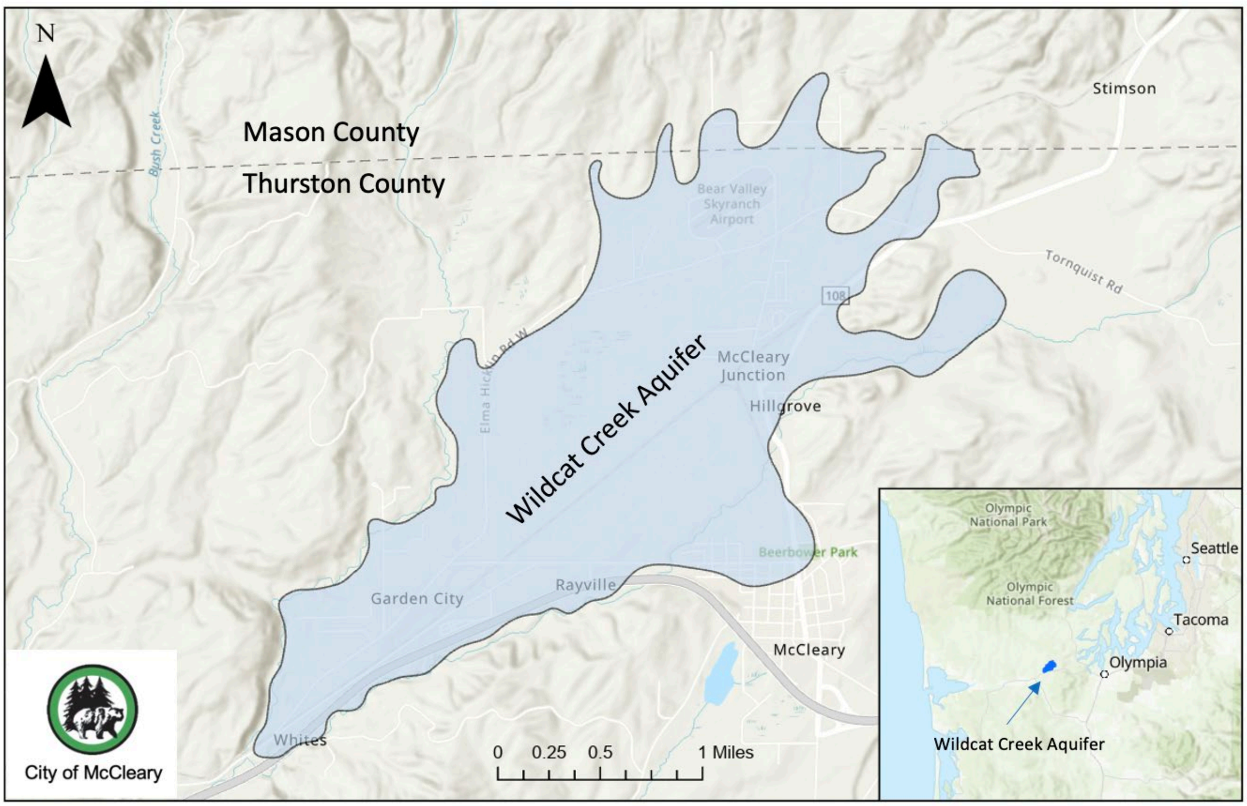

Figure 1. City of McCleary and boundary of the Wildcat Creek Aquifer.

Community Outreach

Community outreach efforts included forming an ASP Board which involved recruiting concerned citizens, including a member supporting habitat restoration interests, and county and local officials. The

[1] Ch. 173-522 WAC

ASP board was instrumental in communications about the project to the community. This allowed for stakeholders to relay personal experiences and stories with respect to water use in basin and to express concerns over the future use of the aquifer. To provide a conduit for communication, an ASP website was created on the City's webpage, with a survey posted to allow users to anonymously submit comments. The survey produced 34 responses, mostly competed by residents within city limits. The majority of survey responses showed a high degree of concern over water supply (Figure 2).

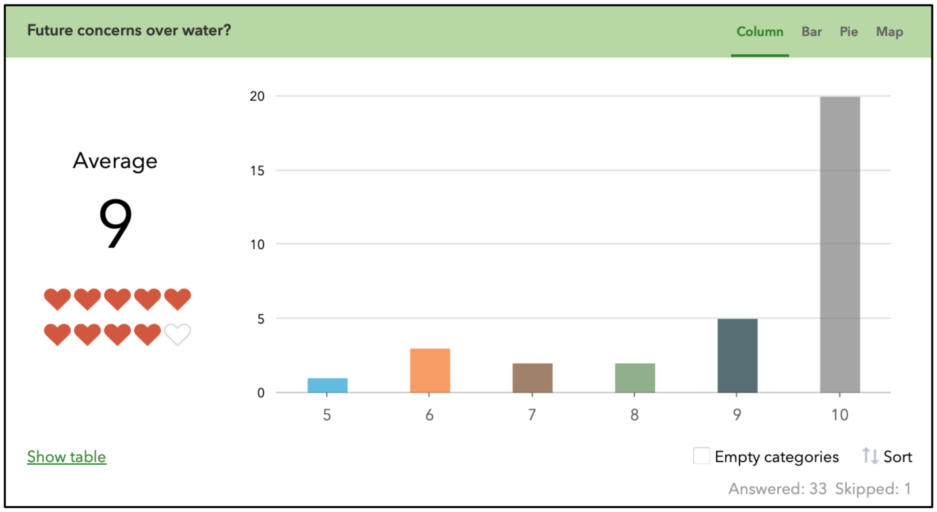

Figure 2. Survey participants were asked to rank future concerns over water supply. All participants ranked their concerns at least 5 out of 10, with an average ranking of 9 out of 10.

Previous Research

Aquifer Conditions

Extensive research to describe the aquifer conditions was undertaken in 1994 and in 2008. The Hart Crower Report (1994) determined clay lenses existed within the basin, sometimes creating perched aquifers overlying the clay. The report produced capture zones for city wells for 1-, 5-, and 10-year travel times. A groundwater flow map was derived using data from 16 wells that showed groundwater flow directions which generally followed topography. A recharge area for City wells was also estimated based on available information. In 2008, the Horsley Witten Group and the Arthur and Pacific Groundwater Group reassessed the aquifer and updated the hydrogeologic conceptual model to include a semi-confined to confined layer of till, rather than isolated lenses of clay. Although 200 well logs were used to distinguish this new layer, a geologic representation of the aquifer was not provided, likely due to the difficulty of identifying wells with respect to exact locations.

The geologic history of the basin extends beyond the boarders which encase it. Initially the aquifer was thought to be composed of glacial sediments from the most recent ice age, however it was later determined the principal aquifer sediments were derived from glacial advances that occurred approximately 100,000 years ago[2]. During this time advanced glacial outwash was covered by

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[2] Arthur, J. & Pacific Groundwater Group, 2008. *Wildcat Creek Aquifer Hydrology, Regulatory Alternative, and Recommendations - Final Report*

discontinuous till, followed by a thin veneer of non-water bearing sediments. The aquifer was overlaid around the preexisting, older basalt to the east, and the younger shale derived from marine sediments to the west (Figure 3).

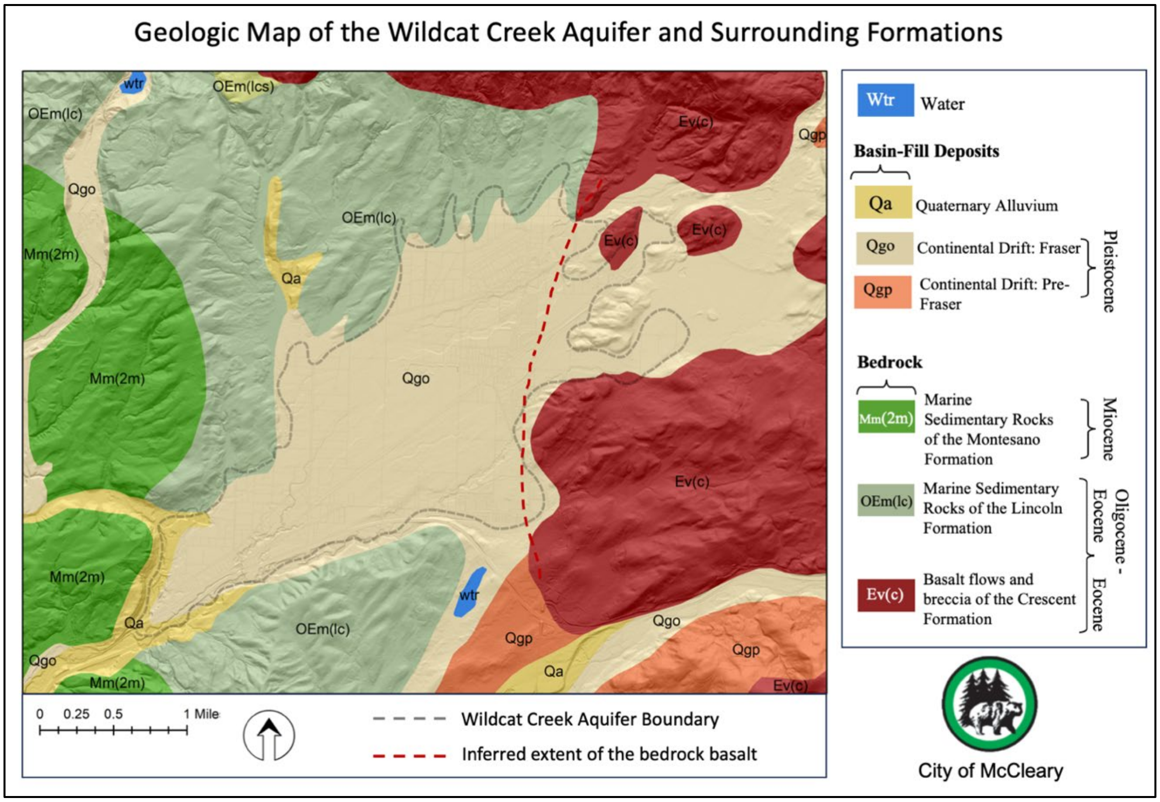


Figure 3. Geologic map surrounding the Wildcat Creek Aquifer

Refining this conceptual model required evaluating well logs to determine formation depth and thickness. A total of 77 well logs were identified that could be located by street address in the basin, which provided an approximate location of the well and water level at the time of construction. These data were used to reproduce groundwater elevations and delineate surficial material. Previous knowledge suggested a layer of till was thin in nature and discontinuous; however, the current conceptual model shows till is widespread and up to 72 feet think in some locations. The thin surficial veneer of non-water bearing sediments, assumed by earlier investigation to contain no domestic wells, was also redefined as Aquifer 1. Although not laterally extensive, domestic wells do withdrawal water from this unit which ranges in thickness from 3 to 62 feet. Although the lower aquifer, designated Aquifer 2, produced similar characteristics as previously investigated, many wells also access the underlying shale. Recently drilled wells in the southwest corner of the basin terminate in the shale. Although previously considered a bedrock unit, the shale maintains some water bearing capacity and is used for domestic water supply (Figure 4)

The till and upper aquifer play an important role in groundwater resources. The till can act as a barrier to contamination, while Aquifer 1 can be a conduit to the lower aquifer, where till is not present and Aquifers 1 and 2 are directly connected. These refinements are important when managing the City's well capture zones and recharge areas. Groundwater recharge to Aquifer 2 is thought to occur mostly along the upland edges of the aquifer, however, exposure to the lower aquifer via windows in the till suggests recharge also takes place on the surface of Aquifer 1.

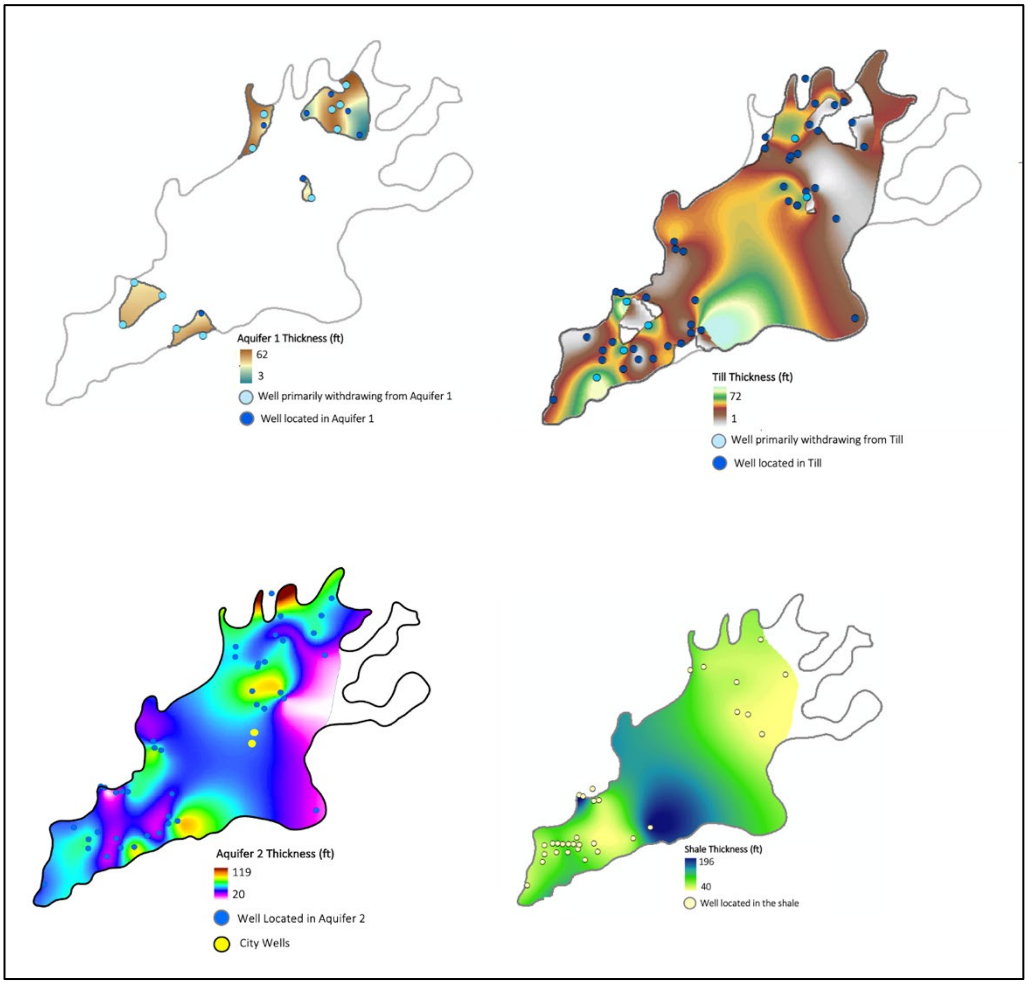


Figure 4. Thickness and spatial distribution of units within the Wildcat Creek Aquifer.

Static Water Level

Static water levels in the aquifer appear to be stable. Measurements obtained in Fall (2022) and Spring (2023) in 5 wells showed an average change of 3 feet. Although historically static water level by formation can vary up to 30 feet, overall respective water level variances range between 10 to 15 feet (Figure 5). This is also supported by an overall historic increase in precipitation.

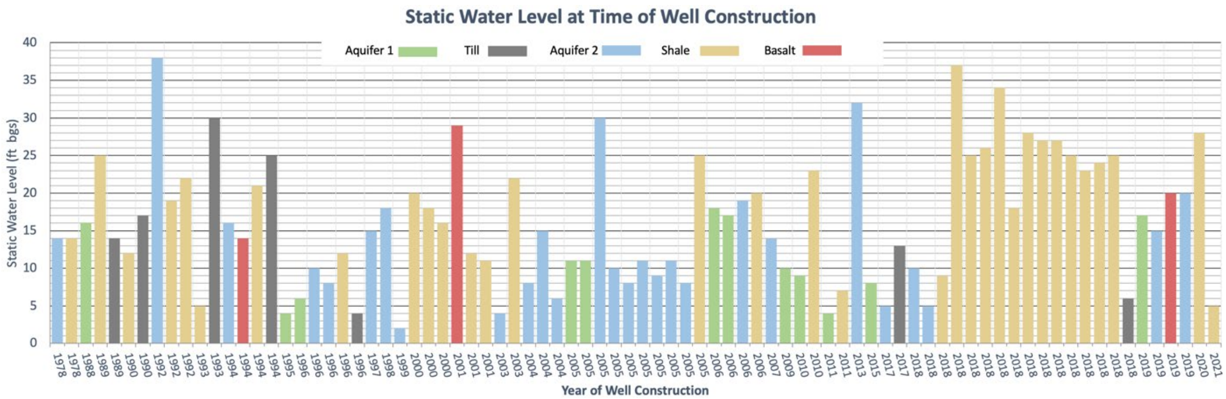


Figure 5. Static water levels of wells, by formation, in the Wildcat Creek Aquifer at the time of construction.

Current Climate Conditions
Available data indicate precipitation and temperature have and are likely to continue to increase over time. This trend has been observed in Grays Harbor County since 1895, with a 0.14 inch per decade increase in precipitation, and a mean average temperature increase of 0.2^{o} F per decade. Mason County shows similar trends. Although increased precipitation is likely to increase groundwater recharge, warmer temperatures may increase evapotranspiration and extend the growing season.

Dry Wells
Concerns over reduction in domestic well productively or complete loss of water supply was reported by residents in and around the basin. Although static water levels suggest the aquifer is prolific and maintains stable conditions, reduction in well capacity is possible, assuming no mechanical well performance issues.

Many issues can cause wells to decrease in capacity. Water level in a well is determined by pumping rates, storativity, and transmissivity of the aquifer. Storativity of an aquifer is the addition or release of water to the storage space due to the increase or decrease of hydraulic head. Transmissivity is the thickness of the aquifer multiplied by the hydraulic conductivity, most simply defined as the ease in which groundwater moves thorough the aquifer.

As a well withdraw groundwater, a cone of depression forms. The shape of the cone, and the water level in the well, is dictated by the pumping rate and inversely proportional to aquifer transmissivity and aquifer storativity. A cone of depression is formed as water is removed from storage. When two wells are in close proximity, well interference may occur, causing two cones of depressions to overlap. This reduces water availability for both wells. Well interference can be avoided by properly designing and spacing out wells where the water level remains undisturbed.

Although every attempt was made to locate well logs for wells reported to have gone dry, none were available to ascertain the formations in which the wells accessed. In general, the locations of these wells suggest most access the shale, which is less transmissive than Aquifer 1 and Aquifer 2. Recent developments along the southwestern portion of the aquifer (Figure 6) show most new wells were drilled in this unit. Given the close proximity to each well, it is possible water levels in the area declined due to well interference and potentially dewatering the water bearing zone within the shale.

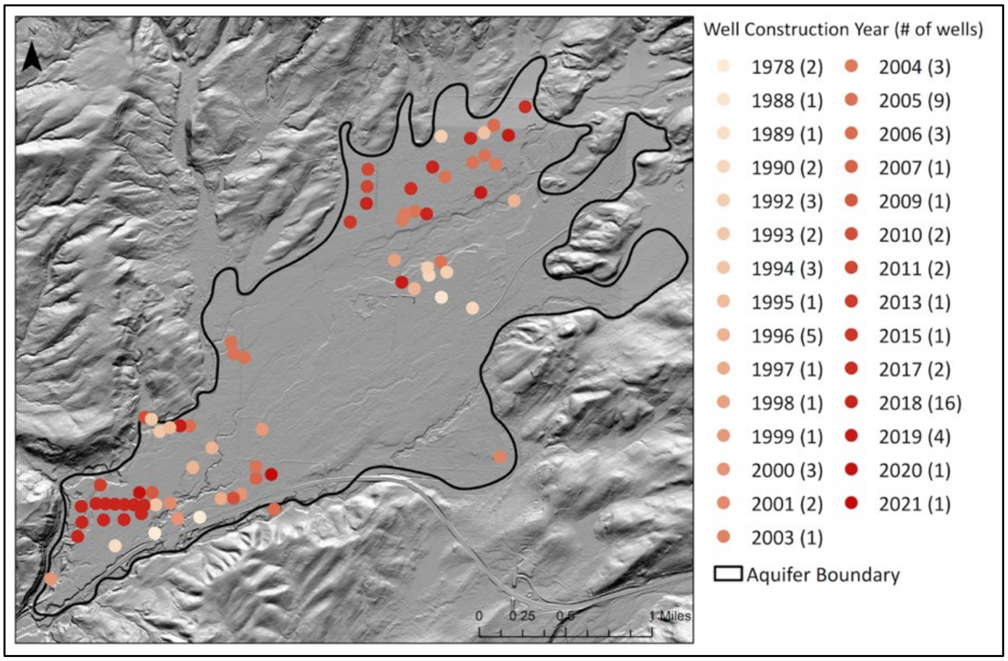


Figure 6. Well construction by year.

Results and Discussion

Aquifer management areas should be designed to prevent degradation of groundwater quality and quantity. The following proposes designating locations throughout the aquifer in areas most vulnerable to contamination or maintain high impact potential due to land use changes.

Attention should be given to locations where till is not present. Although Aquifer 1 potentially filters out some contaminants, where till is absent (Figure 4), it maintains a high degree of connectivity to Aquifer 2 and may act as a conduit for chemicals and pollutants. The Hart Crowser (1994) and the Horsley Witten Group recommended constraining certain activities within the recharge and capture zones to reduce potential contamination. These recommendations can be further refined to areas where till does not underlie Aquifer 1. Near city wells, precautions should be taken to prevent contaminants from entering Aquifer 2, since the city wells are located downgradient from an exposed portion of the aquifer, thereby increasing the likelihood of contaminants leaching into the public water supply (Figure 7).

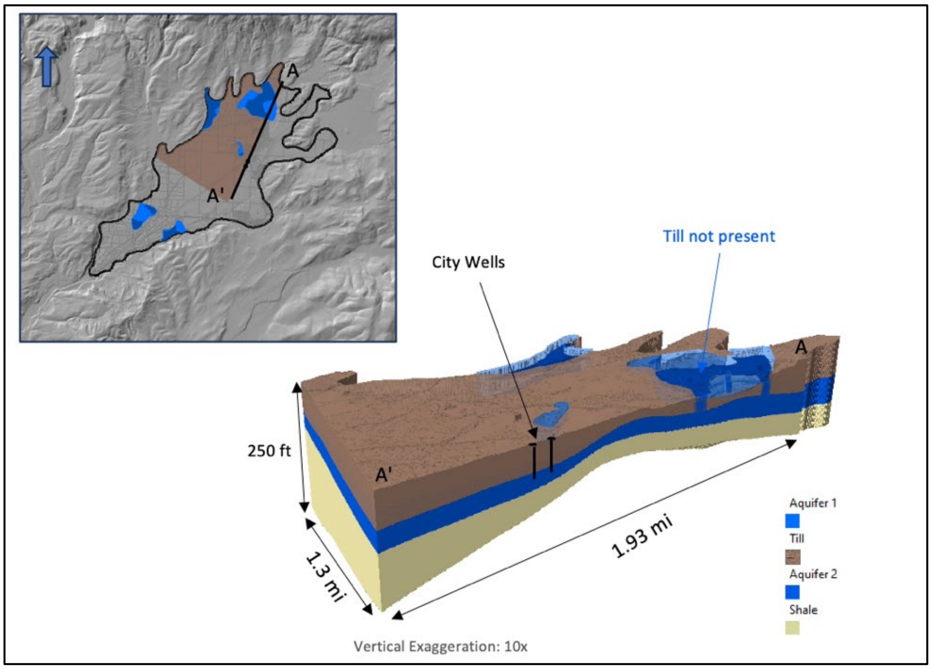


Figure 7. Geologic cross section adjacent to city wells

The recharge area to wells should be designated as an aquifer management area, as recharge likely occurs along the upland boundary. To delineate aquifer conditions in this area requires additional boreholes to evaluate the extent of the boundary area along the northeast fingers where no wells with boring logs exist (Figure 8).

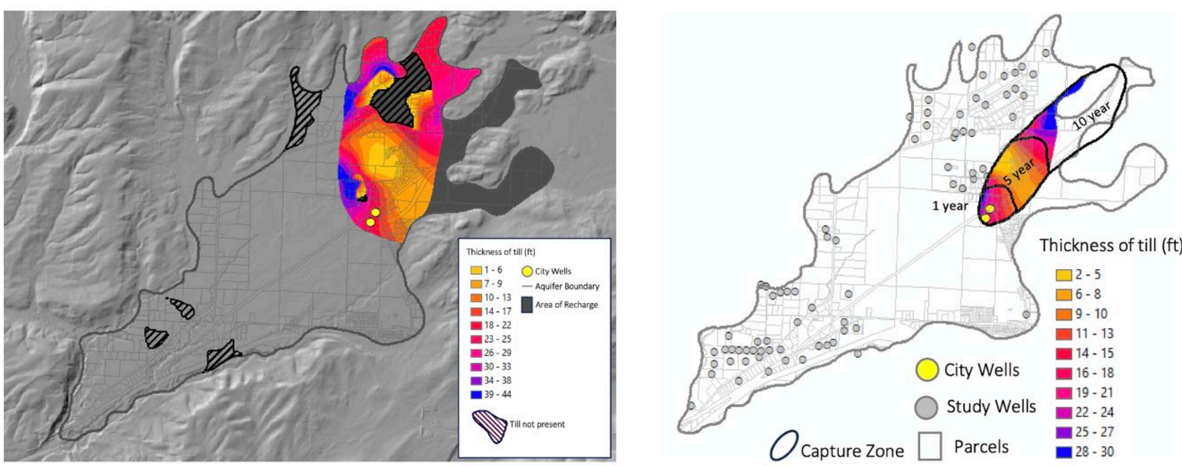


Figure 8. Recharge area and capture zone with respect to thickness and location of till

Standing water within private property, on the northwest section of the aquifer, was reported as a common occurrence. This condition is likely in areas where till is close to the surface, which increases runoff or where upward hydraulic gradients occur. Timber harvesting can also impact surface flows. Harvesting mature trees can lead to a decrease in evaporation and an increase in peak flows or more rapid drainage and higher fluctuations between peak flows. Harvesting timber within the central portion of the aquifer (Figure 9) should be investigated for the likelihood of downgradient alterations in water conditions, which could increase standing water in unwanted locations, after tree removal.

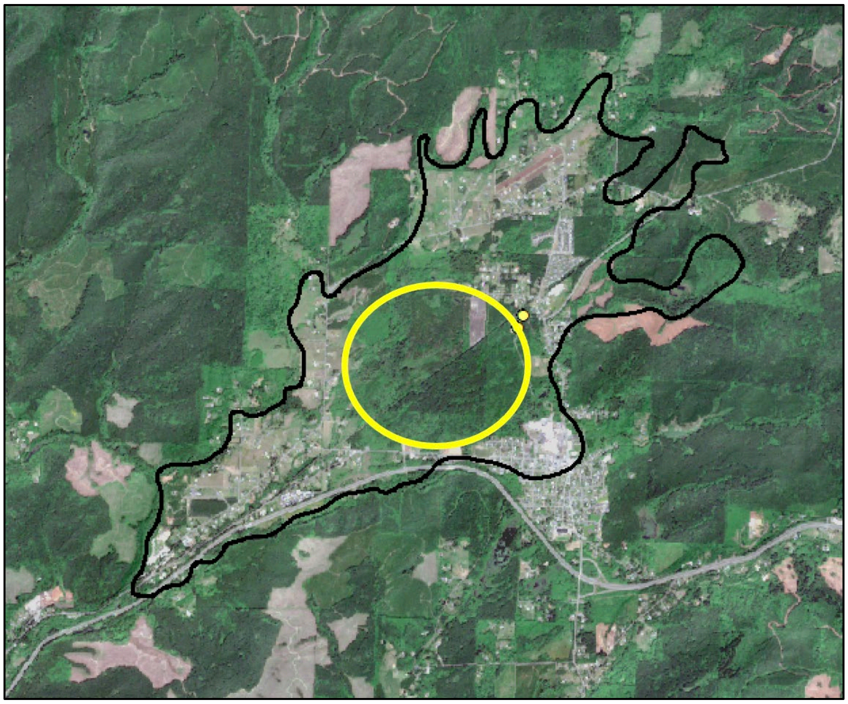


Figure 9. The central portion of the aquifer (yellow circle) where timber harvesting may cause unwanted conditions downgradient.

Recharge to the aquifer likely occurs along the upland margins of the basin. Although no direct evidence supports changes in groundwater conditions when logging occurs at higher elevations along the boundary, future impacts on groundwater resources may develop, if extensive timber is removed.

Water well construction within the basin should be tracked to estimate consumptive water use, and define and implement mitigation strategies to protect streamflow in Wildcat Creek from new consumptive uses (per Ch. 90.94 RCW).

Project Management Actions

The following describes the projects proposed to fill data gaps, evaluate management options, and encourage public outreach.

Project 1: Monitoring, Testing, and Modeling

Additional monitoring and testing are required to improve our understanding of aquifer conditions and to model safe yield scenarios. The following discusses the monitoring projects.

Northeast Upland Boundary: conduct test borings and observation well installation on the northeast portion of the aquifer where groundwater flow data is sparse. This will allow for monitoring of seasonal groundwater fluctuations and enhanced understanding of recharge to the aquifer.

Wildcat Creek: install a staff gauge below the confluence of the Wildcat Creek to systematically measure flows throughout the year, especially during the dry season. Gages in one or more of the forks could also be useful.

City Wells: record water level and pumping data at the City's water supply wells.

Vertical Hydraulic Gradient - Near City Wells: characterization of the vertical hydraulic gradient between the upper and lower aquifer can be accomplished (as recommended in Horsley Witten Group, 2008) by installing monitoring wells along a 20-, 100, and 400-foot transect from the pumping wells. Two wells accessing the shallow and deeper aquifers should be installed at each site.

Vertical Hydraulic Gradient - Southwest Area: observation wells should be installed where till is not present in the upper and lower area of the aquifer, with at least two multi-level wells at each site to to determine vertical gradients, especially where standing groundwater in the lower portion of the basin has been reported.

Modeling: basin-wide modeling will assess the extent water can be pumped from the aquifer without causing unacceptable harm, in addition to evaluating different management scenarios.

Project 2: Water Quality Testing and Land Use Evaluation

Water Quality Testing

Septic system failure poses a threat to water quality. To identify the extent in which nitrates may contaminate drinking water requires a private water quality testing program, especially in locations where till is not present and septic system density is high. Testing should take place every few years. Additional testing for pesticides and household contaminants would provide background concentrations that could be used to test for changes in future conditions.

Land Use

Additional evaluation of water quality concerns on current and future land use changes upgradient of the city wells should be conducted to reduce contaminants entering the aquifer where till is not present.

Project 3: Evaluate Ordinances

Sole Source Aquifer Protection Program: The City of McCleary could petition EPA to evaluate the Wildcat Creek Aquifer for sole source aquifer designation. Doing so could also afford additional protection of the aquifer at the state level.

Project 4: Improve Reliability of Water Supplies for Basin Users

Utility expansion: the city could evaluate the feasibility of extending services to new private groundwater users in the basin to limit the installation of new septic systems and prevent leaching of nitrates.

Project 5: Managed Aquifer Recharge

The City should apply for a Streamflow Restoration Grant from the Department of Ecology to identify suitable locations and implement a **Managed Aquifer Recharge** (MAR) Program for the purpose of protecting streamflow in Wildcat Creek. The MAR program would be designed to capture and store water when available (during high precipitation months) for enhanced aquifer recharge for the purpose of providing additional baseflow to Wildcat Creek that could mitigate for consumptive uses of groundwater withdrawals in the basin.

Project 6: Public Outreach

The City should provide public education material on the aquifer, potential contaminants, and a water well owner's handbook that discusses well efficiency, construction, and maintenance on its website, and provide an avenue for residents to submit possible overdraft issues.

1 Introduction

In 2022, the city of McCleary (City) initiated the Aquifer Sustainability Plan (ASP) project in response to concerns over groundwater quality and quantity of the Wildcat Creek Aquifer. The Wildcat Creek Aquifer supports all users in the basin, including McCleary's water supply. The Department of Ecology has closed Wildcat Creek between May 1 and October 31 by rule[3], meaning no water is available for appropriation from the creek and no unmitigated consumptive groundwater use should be approved that captures water from the creek during the closed period. To address long-term use and protection of the aquifer, McCleary developed the ASP as a framework to achieve long-term reliability over a 20-year horizon. The following describes the Wildcat Creek Aquifer, the framework which ASP supports, and our current understanding of the aquifer. Achieving the objectives of the ASP project required engaging stakeholders and working alongside the public to better understand groundwater's role in the community and ways in which it can be sustainably developed and protected.

1.1 Plan Area

The city of McCleary, home to over 2000 residents, is located in Grays Harbor County, which is approximately 21 miles west of Olympia, Washington. The Wildcat Creek Aquifer underlies portions of the City, Thurston County, and Mason County. The aquifer trends northwest to southeast and covers an area of 4.3 square miles (Figure 1).

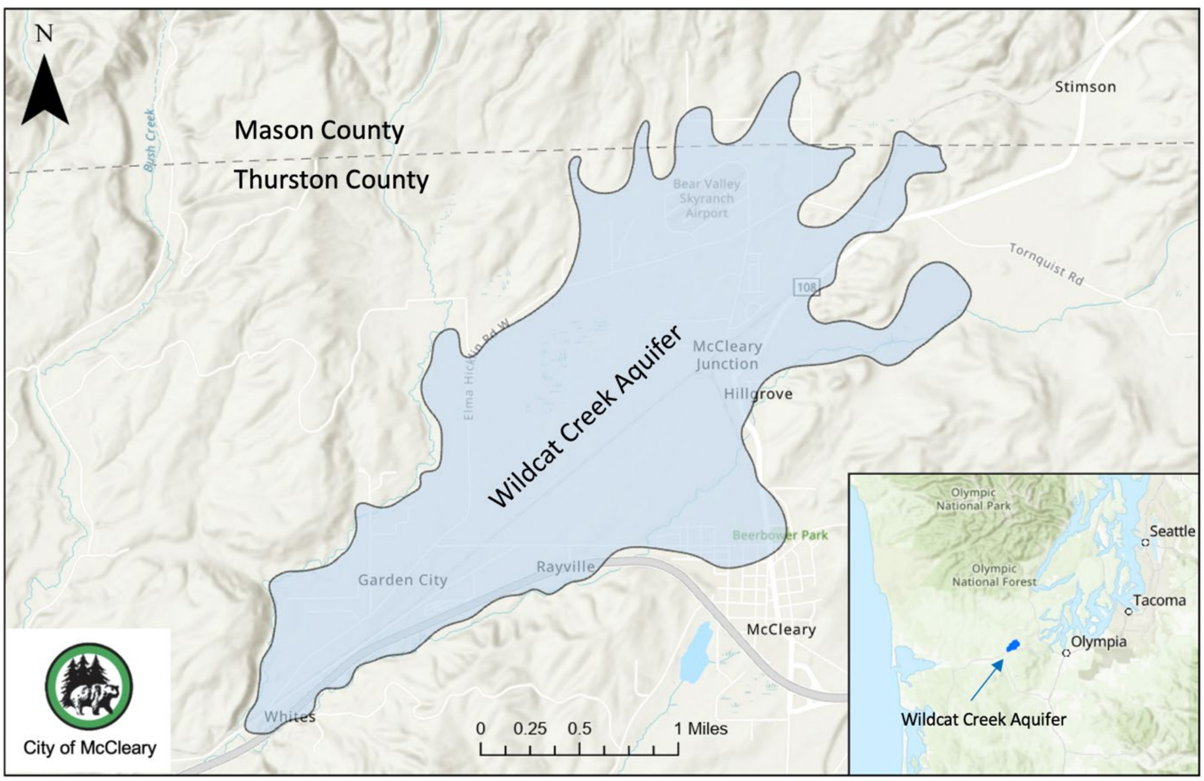


Figure 1. City of McCleary and the boundary of the Wildcat Creek Aquifer

[3] Ch. 173-522 WAC

1.2 Aquifer Sustainability Plan Board

A stakeholder engagement strategy was created to ensure a comprehensive approach was incorporated into the ASP, which attempted to consider all groundwater users in the basin. The strategy involved creating an ASP Board, which included concerned citizens and government agencies, including city and county representatives. The Aquifer Sustainability Plan Board is responsible for determining the approach and project strategies designed to achieve sustainable use.

1.3 Community Outreach

To reach as many stakeholders as possible, an outreach plan was implemented to gauge community interest and concerns over water resources. A website was created to house the ASP project as a community resource. A survey was conducted to evaluate local concerns over water supply, and more than 20 residents in the basin were interviewed through phone or in-person. This provided an opportunity for members of the community to share their history in the basin and their experiences and observations of water resources.

1.3.1 Website

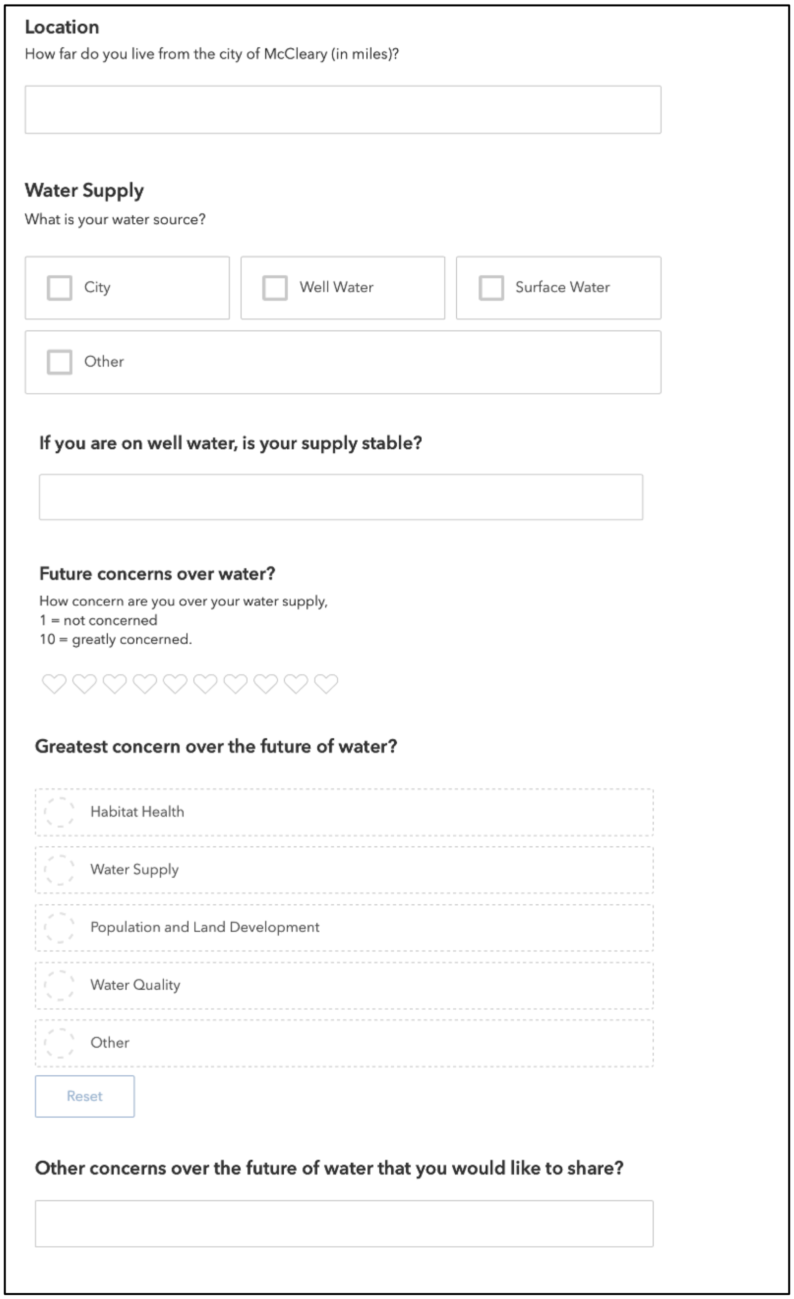
The city of McCleary's ASP website (Figure 2) was created to provide public access to ASP documents, meeting recordings, information on the aquifer, and to post a community survey on the aquifer allowing the user to rate concerns over water supply and post anonymous comments.

Figure 2. Home page of the city of McCleary's Aquifer Sustainability Project Website.

1.3.2 Survey

A community survey (Figure), posted on the ASP website, posed questions to assess community interest in water supply and to provide a community platform to relay anonymous concerns. A total of 34 participants filed out the survey, mostly within city limits (Appendix A). No question was required;

therefore, not all questions received responses. Out of 30 participants, 56% rely on city water and the remaining rely on private well water. Those that are on well water were asked if their water supply is stable. Of the 12 that responded, 6 marked yes, with 1 individual stating their well went dry due to new homes in McCleary (Figure 10).



Location

How far do you live from the city of McCleary (in miles)?

Water Supply

What is your water source?

- City
- Well Water
- Surface Water
- Other

If you are on well water, is your supply stable?

Future concerns over water?

How concern are you over your water supply,
1 = not concerned
10 = greatly concerned.

Greatest concern over the future of water?

- Habitat Health
- Water Supply
- Population and Land Development
- Water Quality
- Other

Reset

Other concerns over the future of water that you would like to share?

Figure 3. The ASP community survey

If you are on well water, is your supply stable? Word cloud

The word cloud requires at least 20 answers to show.

Hide table · Show words

Response	Count
Yes	6
Unknown	1
Think so	1
So far, yes, over 33 years.	1
No. It has ran dry since the new homes projects where placed in McCleary	1
Fairly stable	1
City well seems to provide.	1

Answered: 12 Skipped: 22

Figure 10. Survey response from participants withdrawing groundwater from wells.

Participants were also asked to rate their concerns over the future of water in the basin from 1 to 10. All of the 33 participants ranked their concerns at least 5 out of 10, with an average ranking of 9 out of 10 (Figure 11).

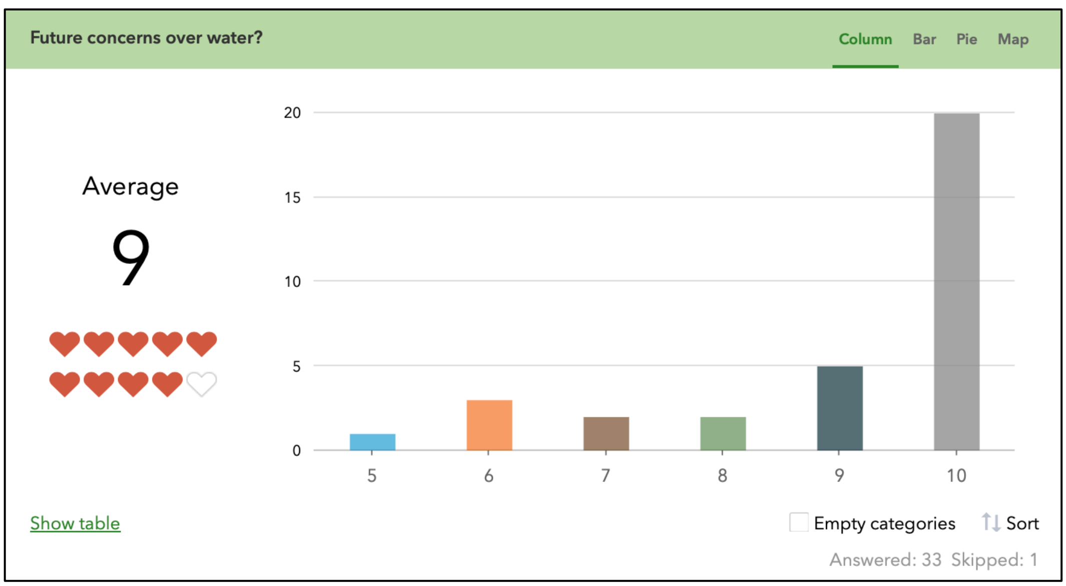


Figure 11. Survey participants were asked to rank future concerns over water supply. All participants ranked their concerns at least 5 out of 10, with an average ranking of 9 out of 10.

2 Previous Research

2.1.1 Hart Crowser, 1994

Research investigating the Wildcat Creek Aquifer dates back to Hart Crowser (1994), *Hydrogeologic Characterization for Protection of the Wildcat Creek Aquifer*, which characterized the hydrogeology of the basin to determine where land use activities may impact groundwater withdrawn by the City. The final report included recommendations for protecting the water supply, and delineated wellhead protection areas based on time-related capture zones. The capture zones are areas where contaminants may enter the groundwater and travel to the wellfield within a specific period of time. The primary areas were defined as 1-, 5- and 10-year capture zones. The Hart Crowser report also defined the following:

- The extent of the aquifer
- Groundwater flow conditions
- Aquifer hydraulic properties
- Preliminarily identified land use that may impact groundwater quality
- Recommendations for the development of a wellhead protection plan

To achieve these objectives, 16 domestic wells were measured for depth to water, which were then used to create a groundwater flow map of groundwater elevations and path of movement in the aquifer. An aquifer pumping test was conducted to collect data to estimate the permeability of the aquifer within the city's two wells.

Land use surveys were conducted through field reconnaissance with point and non-point sources of contamination (Figure 13). A total of 17-point sources were identified, which included current and former gas stations, the city's maintenance shop, timber and automotive related business, and the cemetery. Nonpoint sources of concern to the city's wellfield included the Burlington Northern Railroad, Highway 108, and unsewered homes along the Elma-Hicklin Rd.

A hydrogeologic conceptual model was developed and incorporated into modeling tools used for defining capture zones. Geologic interpretation was developed from field reconnaissance and existing driller well report information, with additional information pulled from regional data and extrapolated to the basin.

The conceptual model showed a sequence of recent alluvial and glacial sediments overlying bedrock to depths of up to 100 feet, with the boundary of the aquifer generally following the bedrock topography. Within the valley, the first 10 to 20 feet of deposits are composed of silt, sand, clay, and peat – likely alluvial in origin, which are underlain by glacial outwash materials that formed the aquifer. The outwash consists of reasonably permeable sand and gravel with some silt and clay. It was concluded that a finer-grain alluvial material, which is less permeable than the aquifer, overlie sections of the aquifer, and is relatively thin and variable in character.

The report characterized groundwater levels at depths of 10 to 20 feet below the ground surface, with the fine-grained materials at the surface creating a partial confining layer in many locations. Recharge to the aquifer was assumed to occur from direct precipitation. A groundwater gradient of 0.009 ft/ft was estimated, while discharge was predicted to enter Wildcat Creek as it leaves the valley to the southwest.

Aquifer characteristics were determined based on testing of well MC-2 and showed a slowing of the rate of drawdown after 2.5 hours of pumping, indicating a leaky confined aquifer with a transmissivity of 25,000 to 30,000 gallons per day/foot and a storage coefficient of 0.001 (Figure 12).

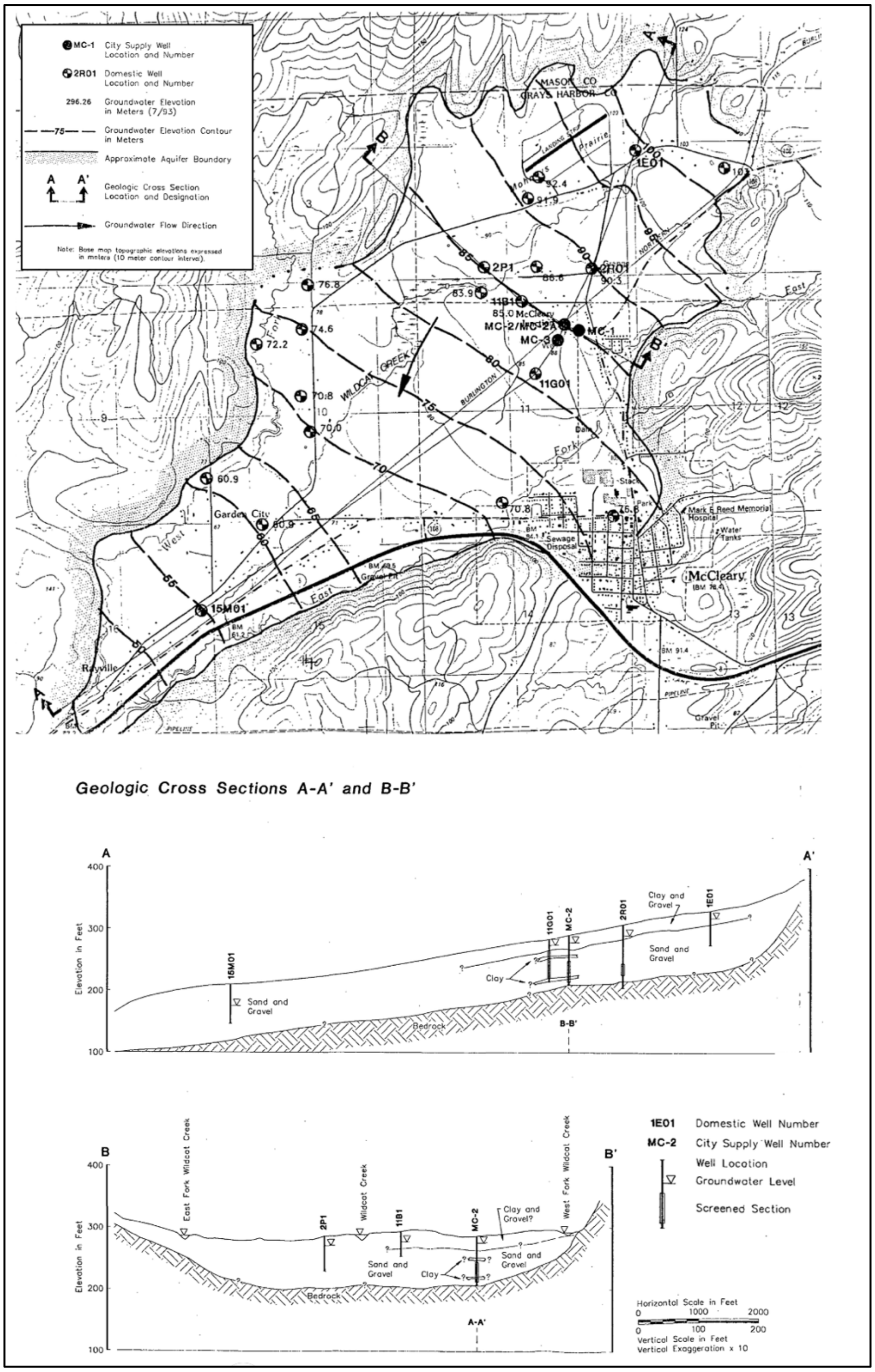


Figure 12. Well location and cross sections developed in the Hart Crower Report (1994)

The primary area for recharge – infiltration of precipitation to the aquifer – was assumed to occur along the boundary of the aquifer, with additional recharge received from runoff in the surrounding area of the Wildcat Creek drainage (Figure 13). It was determined groundwater elevations coincident with the Wildcat Creek elevation in the 90- and 100-meter contour suggested some surface/groundwater interaction occurs.

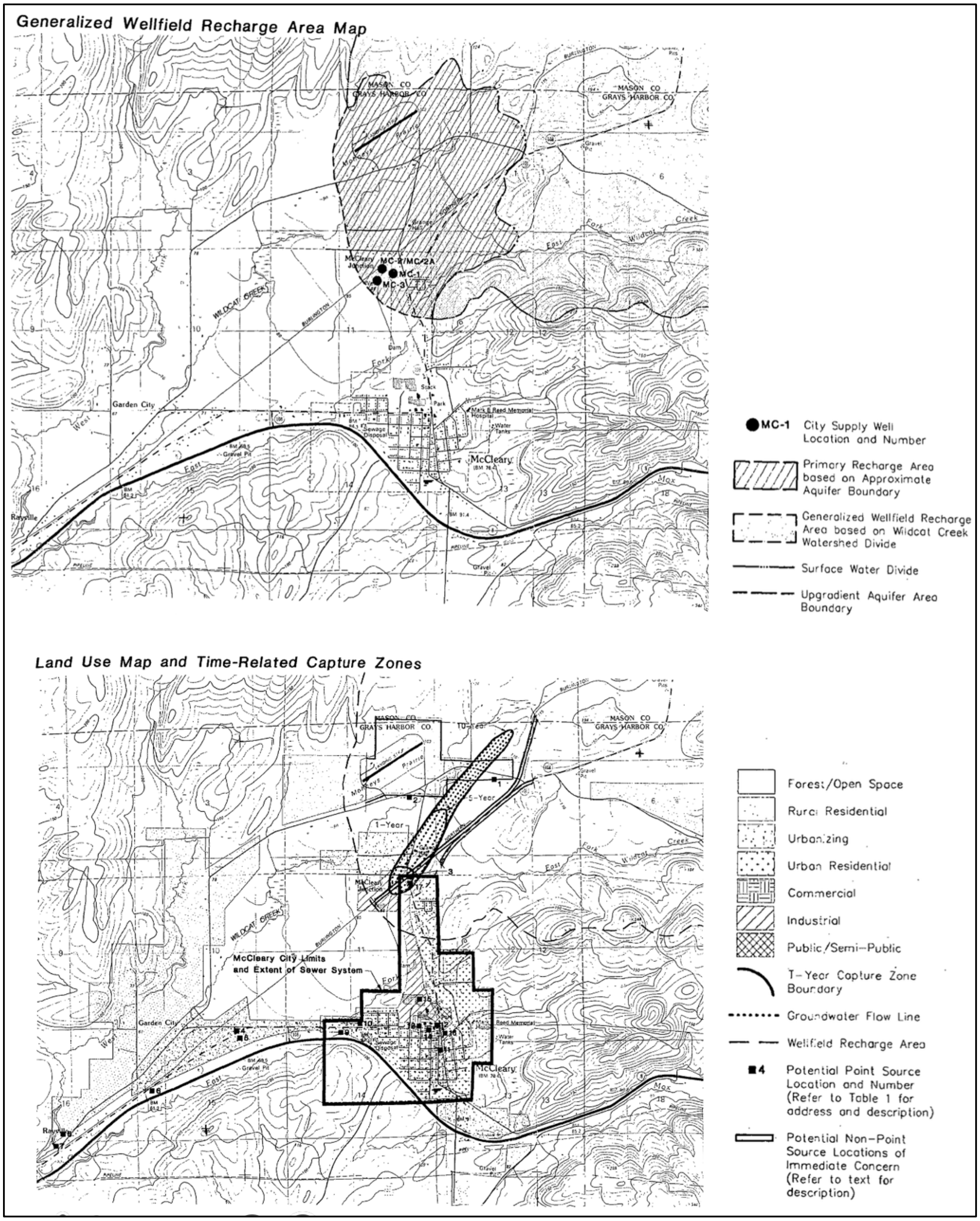


Figure 13. Generalized Wellfield Recharge Area Map; Land Use Map and Time-Related Capture Zones in the Hart Crowser Report (1994)

The wellfield capture zones were determined based on modeling, which included a groundwater flow model that predicted groundwater elevations were data gaps existed. The capture zone was estimated by defining groundwater flow paths based on modeled groundwater elevations and calculating travel times along the path based on hydraulic conductivity values.

The researchers concluded the McCleary water supply is most vulnerable to contamination northeast of the wellfield, within the capture zones defined in the report (Figure 12). The following recommendations for wellhead protection were based on the vulnerability of the aquifer and the lack of an existing alternative water supply for the City:

- **Notification**: inform persons responsible for the identified contaminant sources that they are located in a wellhead protection area
- **Education**: conduct public outreach and educational program concerning the water supply and potential means of contamination.
- **Labeling**: install wellhead protection area boundary signs for transportation corridors.
- **Petition**: petition the Environmental Protection Agency to designate the Wildcat Creek Aquifer as a sole source aquifer
- **Establish**: due to uncertainty in the capture zones, it was recommended to apply management strategies to the entire aquifer recharge area upgradient of the wellfield. Although this includes redefining the capture zone to reduce uncertainty and define a more reliable wellhead protection area.

Other recommendations included the development of a wellhead protection program, including establishing a local wellhead protection committee and conduct a more detailed source assessment. The assessment should include a field search for domestic wells, especially decommissioned wells, that may be a conduit for contamination to reach the aquifer; determine if nitrates from residential septic systems are a potential source, and identification of specific threats associated with properties, such as hazardous chemicals, underground storage tanks, etc.
A summary of the wellhead protection recommendations included:

- **1-year Capture Zone**: water supply should be protected from microbial contamination and direct chemical contamination, and chemicals capable of contaminating groundwater should not be stored or used unless sufficient measures are taken to protect groundwater.
- **5-year Capture Zone:** management should be similar to the 1-year capture zone, with an emphasis on pollution prevention and risk reduction management.
- **10-year Capture Zone**: although source management in this zone may be less active, high-risk sources should be identified and actively managed. The zone is defined to encourage planning to recognize the long-term source of drinking water to allow the community to plan and site future high-risk sources outside the area of recharge.

- **Source Management Options within the Capture Zones:**
  - *Source Removal:* potentially extending city sewers if nitrates are a problem to replace septic tanks, and the removal of household hazardous waste collection to decrease the possibility of improper disposal and accidental spillage.
  - *Land Use Management:* zoning changes in the wellhead protection areas should be changed to prevent industrial and urban-type land uses from locating in the capture zones.
  - *Ordinances:* groundwater protection ordinances to include facility design requirements, operating standards, and direct spill reporting requirements for facilities located in the capture zones.
  - *Groundwater Monitoring:* groundwater monitoring network installed within the wellhead protection area to aid in early detection of contaminants and provide a basis for requesting enforcement of water quality standard violations by Ecology.
- **Prepare a Contingency Plan**: a contingency plan should be prepared to address emergency replacement of the water supply source if it were to be contaminated. Options include the following:
  - Identify a back-up well or feasible interties with other water systems, with the location should be developed based on land uses and groundwater flow directions, with potential sources of contamination not located upgradient from it.
  - A spill response plan, which documents coordination with local first responders, and updated every two years or more if the situation warrants.

2.1.2 Horsley Witten Group, [Jan] 2008

The Horsley Witten Group conducted a case study, *City of McLeary Public Water Supply Wells,* which assessed current conditions of the City's water supply with respect to water quantity and water quality, and also provided recommendations for protection and management strategies for future growth to both county and city officials. The study was also designed to provide guidance to Grays Harbor County residents who rely upon private domestic wells for water supply.

The case study included the following:

- **Assessed the amount of groundwater available for the McCleary's public drinking water supply wells**: this included conducting a hydrologic budget and safe yield analysis.
- **Buildout Analysis**: the buildout analysis evaluated the zoning in the County lands within the recharge area to determine the number of new homes and respective septic systems.
- **Nitrogen loading analysis:** this analysis was conducted on baseline conditions and buildout, since the potential threat to the regional drinking water supply is increased development in the area.

The findings from this case study included the following:

- The concept of an upper and lower "leaky confined aquifer" not derived from alluvial processes, as described in the Hart Crower Report (1994) but glacial processes. The confined unit is glacial till.
- Local experts in the area surrounding the public water supply wells believe the deeper aquifer is confined and under pressure, with an upward hydraulic gradient, and the wells may be partially screened in both the upper and lower aquifer.
- The final hydraulic budget focused on natural recharge and public wells. The budget assumed 10% of surficial recharge enters the lower confined aquifer, with 90% of lateral flows through the upper aquifer. The City wells were estimated at withdrawing an average of 105 million gallons per year from the confined aquifer, which is approximately 14% of the estimated 773 million gallons per year that is predicted to recharge the aquifer. Although that leaves 86% percent of the groundwater within the aquifer, that does not mean the surplus can be withdrawn and the maximum withdrawal rate should be established through a safe yield analysis that incorporates vertical hydraulic gradient considerations.

	Area (acres)	Recharge (inches/year)	Flow (Q) (M gallons/year)
Recharge			
Primary Recharge Area	819	2.4	54
Buffer Zone (Secondary Recharge Area)*	11,000	2.4	719
Total	11,819		773
Withdrawals			
Total withdrawal volume from public wells			105
Total			105

Table 1. Hydrologic Budget for Lower Confined Aquifer in the Horsley Witten Group Report (2008)

- It was estimated that significant amounts of groundwater in the upper unconfined aquifer is flowing laterally and discharging to the stream, which equates to 57 and 331 million gallons per year, given the season of measurement.
- The buildout analysis indicated the zoning in the County lands within the recharge area will allow for 385 homes with septic systems to be built.
- Results from the nitrogen loading analysis show natural concentrations of nitrate-nitrogen in groundwater are less than 0.1 milligrams per liter. The predicted high existing nitrogen loading to the upper aquifer (1.6 mg/liter) and the low measured baseline concentrations in the public supply wells (0.2 mg/liter), indicates that the confining layer is providing a significant level of protection to the lower aquifer.

A recommended approach and strategy were offered as a means to protect water quality and quantity. A summary of the recommendations includes the following:

- The smart growth[4] technique was recommended as a way to increase growth, vitality, and economic development within the city of McCleary. Two regulatory/smart growth techniques that would be particularly useful to the city of McCleary to maintain growth while providing protection of the public water supply wells include Transfer of Development Rights and Low Impact Development.

- The following discussed below were recommended to better assess existing conditions.
    1. <u>Water Level Monitoring:</u> water level monitoring protocol to further clarify the vertical hydraulic gradient between the upper and lower aquifer units.
        - Installation of three multi-level well clusters (each with a shallow well in the upper and deeper well in the deeper confined aquifer). The well clusters should be installed at distances of approximately 20 feet, 100 feet, and 400 feet from the pumping wells along a transect.
        - Water levels should be measured in each of the six wells using a continuous recording pressure transducer. This data should be plotted and analyzed in relation to pumping records at the two pumping wells.
        - Changes in hydraulic gradient between the shallow and confined aquifers can then be assessed under a range of pumping conditions. These data can then be used to refine a safe yield estimate, defined as the quantity of water that can be safely withdrawn from the aquifer without reversal of the hydraulic gradient and subsequent water quality threats from contaminated water in the shallow aquifer.

    2. <u>Water Quality Testing (Private Wells):</u> To confirm the nitrogen loading results, private wells located up-gradient of the public water supply that draw from the upper aquifer be tested for nitrate. Approximately 30 wells should be sampled and tested, with locations plotted. Only wells that have drilling logs that suggest they are shallow and screened in the unconfined aquifer (less than 30 feet) should be selected.

    3. <u>Private Well Protection:</u> much of Grays Harbor County will continue to rely upon private domestic wells as their source of drinking water. The majority of the wells are shallow and draw from the unconfined aquifer. This aquifer is vulnerable to pollution from nearby land uses including septic systems, fertilizers, and livestock. To provide safe drinking water, the County could consider developing private well protection zones and locating significant pollution sources such as septic systems and livestock away from wells.

        Private well protection zones can include a fixed radius (such as 100 feet) and an extended area up-gradient to take into account groundwater flow direction.

[4] To learn more about the Smart Growth technique, visit: Smart Growth America at https://smartgrowthamerica.org/what-is-smart-growth/ (accessed 6/2023)

4. Public Education: a critical part of any drinking water protection program is public education. Homeowners and business operators must be aware of the sensitivity of the groundwater system and the potential impacts that their individual activities may have. Homeowner practices such as lawn fertilization, application of pesticides, pet and livestock waste management and failing on-site systems all can have direct water quality impacts. Cumulatively, these impacts can add up and may cause significant degradation to the community drinking water supply.

5. Transfer of Development Rights: Transfer of Development Rights (TDR) is a regulatory strategy that harnesses private market forces to accomplish two smart growth objectives.

    - Open space is permanently protected for water supply, agricultural, habitat, recreational, or other purposes via the transfer of some or all of the development that would otherwise have occurred in these sensitive places to more suitable locations.
    - Other locations, such as city and town centers or vacant and underutilized properties, become more vibrant and successful as the development potential from the protected resource areas is transferred to them. In essence, development rights are "transferred" from one district (the "sending district") to another (the "receiving district").

    Communities using TDR are generally shifting development densities within the community to achieve both open space and economic goals without changing their overall development potential. Implementing a TDR program would provide protection of McCleary's public water supply and would also benefit the city by refocusing development attention and growth to the city. Prior to implementing a TDR program, however, the community should attain the following characteristics summarized below:

    - Clearly Identified Resource Areas for Protection.
    - Consensus Regarding the Location and Extent of Receiving Areas.
    - Infrastructure that can support Increases in Density.
    - A clearly written ordinance.
    - Strong Market Conditions
    - TDR Credit Bank.
    - Sophisticated reviewing/permitting authority.
    - Open communication between local agencies.

    TDR Example: A local model applying the TDR program in Thurston County, created a TDR ordinance in 1995 for the purpose of protecting agricultural lands. The sending area for the TDR program consists of any land zoned as "long-term agricultural," a zoning classification required by the state's Growth Management

Act. All of this land is within unincorporated areas of the county and is zoned for one dwelling unit per 20 acres. Landowners in the sending area are entitled to one development right for every five acres of land they own, regardless of whether the land is suitable for development. They are required to reserve one development right for each unit they want to build. The county maintains a list of interested sellers, and development rights are traded on the open market. The receiving areas are located throughout the unincorporated area of the county and within each of the three largest cities. Four ordinances, one for the county and one for each of the three largest cities (Lacey, Tumwater and Olympia), were adopted in 1995[5].

6. Low Impact Development: Decreasing water consumption rates within the city, whether through regulations or incentive programs, is an important consideration to protect the water supply. Not only is water quantity threatened by increased withdrawal and consumption, but in the case of the Wildcat Creek aquifer, water quality is also at risk. It is believed that groundwater within the deeper aquifer is under pressure and currently has an upward flow potential. However, the upward flow potential is dependent upon maintaining an upward gradient and increasing withdrawals may cause the water to flow downward, threatening the drinking water supply with contaminated groundwater from the overlying shallow unconfined aquifer.

   One strategy that could successfully reduce water demand on public drinking water supply wells would be to implement a Low Impact Development (LID) ordinance. The ordinance may require changes to both the City of McCleary's and Grays Harbor County's Comprehensive Plans, zoning codes, design standards, and other applicable regulations. Some of the Comprehensive Plan's primary planning goals include:

   - Urban growth
   - Reduction of sprawl
   - Efficient multi-modal transportation
   - Diverse and equitable housing
   - Economic development
   - Encouragement of natural resource industries
   - Open space and recreation
   - Environmental protection

   LID is a more sustainable land development pattern that results from a site planning process that first identifies critical natural resources, and then determines appropriate building envelopes. LID also incorporates a range of best management

[5] American Farmland Trust, 2001. Purchase a Development Right and Transfer of Development Rights Case Studies. Prepared for the Boone County Planning Commission. pp. 11-15.

practices (BMPs) that preserve the natural hydrology of the land. Best management practices can include bioretention systems, infiltration systems, green roofs, and cisterns to treat, store and re-use stormwater runoff as an irrigation source. The principles of LID are also in direct alignment with the Comprehensive Plan goals.

The LID ordinance could require water conservation devices for public buildings and provide incentives for their implementation in private business and residences. The ordinance should also include design criteria that require the collection and re-use of stormwater as an irrigation source (using rain barrels, cisterns, or recharge to the local groundwater system). This would significantly reduce water demands on the public drinking water system during the growing season and provide water allocation to future growth within the city limits. According to local sources, the winter water demand averages 257 gallons/day per residence. This demand increases to 600 gallons/day per residence during the summer growing season. A significant portion of this increase is believed to be irrigation.

In addition to reducing non-point source pollution to drinking water supplies and surface waters, LID provides other important benefits to the municipality, the developer, and the general public. More concentrated (cluster) design, with less impervious area and smaller infrastructure (stormwater drainage and other utilities), means significant cost savings to developers. Less impervious surface creates less surface runoff, which will decrease the burden to municipal drainage infrastructure.

> *LID Example:* Thurston County and the City of Olympia have adopted LID principles into their Comprehensive Plans, zoning and tree protection ordinances; street, sidewalk, and parking standards; and drainage design and erosion control standards. The Comprehensive Plan amendment process began earlier and took a year, from September 2000 to September 2001. The Olympia Planning Commission reviewed the entire package – the first time it had considered anything other than Comprehensive Plan revisions. During review of the Comprehensive Plan amendments, the chart comparing impacts with conventional and low-impact design helped convince both City and County Planning Commissions that the approach was viable[6].
>
> By adoption of Ordinance 6140 (Olympia's LID ordinance), the City supplemented the Comprehensive Plan's Chapter 1 (Land Use and Urban Design), Chapter 2 (Environment), Chapter 5 (Utilities and Public Facilities), and Chapter 6 (Transportation) with goals and policies that establish Green Cove basin as a unique area, subject to enhanced environmental regulations. Primary goals and policy changes for Green Cove basin included the following:

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[6] City of Olympia, Water Resources Program. 2022. Low-Impact Development Strategy for Green Cove Basin: A Case Study in Regulatory Protection of Aquatic Habitat in Urbanizing Watersheds. Olympia, WA. pp. 1-13.

⇒ Designate Green Cove Creek as a sensitive drainage basin.
⇒ Avoid high-density development where new development would have a significant adverse impact upon the habitat within designated sensitive drainage basins.
⇒ Administer development regulations that protect critical areas and designated sensitive drainage basins.
⇒ Adopt low-impact development regulations within designated sensitive drainage basins that may include stormwater standards, critical area regulations, zoning designations, and other development standards.
⇒ Establish street designs that minimize impacts to the natural environment especially within a designated sensitive drainage basin.

The City of Olympia also used Ordinance 6140 to amend the municipal code with requirements for designated sensitive drainage basins, Green Cove basin in particular. The ordinance created a new zoning district and increased tree protection and replacement requirements. The new zoning district, Residential Low Impact (RLI), applied to Green Cove basin within Olympia's city limits. Parcels along the basin boundary that have at least 50% of their surface area within the basin were included in the district. Traits of the district included:

⇒ Residential densities of two to four units per acre. Duplex, townhouse, and multifamily uses are allowed.
⇒ Lot widths and rear setbacks are reduced, and maximum building heights are increased, compared to the other residential districts.
⇒ Maximum impervious surface coverage per lot is limited to 2,500 square feet.
⇒ Several land uses, including duplexes and parking lots, not typically permitted in single-family residential developments, are allowed in the Green Cove basin.

Olympia also enacted a new Chapter 16.54 Tree Protection and Replacement for Green Cove Basin, which requires a minimum tree density of 220 tree units per acre. The requirement will result in approximately 55% tree cover in any given development.

Thurston County amended their Olympia Urban Growth Area Zoning Code (TCC 20.23), to be generally consistent with City of Olympia zoning. The urban growth area within Green Cove Creek Drainage Basin was rezoned from predominately 4-8 units per acre to 2-4 units per acre. The exception was a forested area along the creek where density was limited to one unit per five acres, to reduce the overall impervious surface in the basin to levels likely to enable preservation of anadromous fish and to buffer the creek from the impacts of urban density development up slope. The zoning amendments also required that, within the urban growth area, 60% of each site be retained in open space and that existing vegetation in these areas be preserved.

7. New Well Construction: A recent communication from City of McCleary officials suggests that the public supply well may be screened partially in the upper aquifer. In the event that the water quality testing confirms the nitrogen loading estimates, Horsley Whitten Group recommends that the City includes the possibility of eliminating the shallow screens using "packers" that could seal off these intake areas and limit the wells intakes to the lower confined aquifer. If this is not feasible another option would be to drill a new well in the confined aquifer.

2.1.3 Arthur & Pacific Groundwater Group, [June] 2008

In the report, *Wildcat Creek Aquifer - Hydrology, Regulatory Alternative, and Recommendations – Final Report,* written *by* Arthur & Pacific Groundwater Group (2008), a description of what is known about the aquifer and recommends actions for its protection and management was provided.

A summary of the formation of the aquifer included a its geologic history, which suggested the Double Bluff glacial period was responsible for the dominant glacial outwash and the overlying till. The description of the aquifer stratigraphy included:

- Bedrock: basalt to the east and south, and sandstone to the west and north
- Advance outwash up to 75 feet thick
- Till which varies from as little as 10 feet to as much as 40 feet thick
- Thin, discontinuous veneer of Vashon outwash
- Alluvial sediments since the last Ice Age (13,000 years ago)

The report reiterated that previous reports written about the Wildcat Creek Aquifer are correct in assuming the presence of a confining layer to the northeast portion of the aquifer, and concluded the confining till layer extends throughout the aquifer; however, the only significant aquifer resides within the advance outwash material beneath the till.

A summary of the findings included:

- There is only one aquifer.
- Both shallow domestic wells and slightly deeper City wells are drilled through the overlying till into this aquifer.
- The semi-confining effect of the till accounts for the upward pressure in the City wells.
- Most recharge percolates down from precipitation falling directly on the land surface overlying the aquifer. There is little contribution via fractures in the basalt.
- Till delays the percolation of rainwater down to the aquifer, providing some protection against contamination but also lowers the recharge rate.

During the course of the analysis, 200 well logs were examined, and it was determined the aquifer material made of up glacial outwash, was not from the Ice Age event that occurred 13,000 years ago, but from the Double Bluff glacial period that took place 100,000 years ago. This was based on the degree of weathering within the till. It was also suggested that the confined aquifer potentiometric surface occurs above the till but does not measure above land surface indicating the aquifer is not artesian, while the water table within the surficial units may reach the surface during winter, forming seasonal wetlands. It was further suggested that the thin outwash and weathered till do not constitute an aquifer, as no known wells tap these deposits; although a few wells appear to tap thin, discontinuous lenses of sand and gravel within the till, but are insignificant in volume compared to the Wildcat Creek Aquifer and do not constitute a second, independent aquifer.

To learn more about the aquifer and safe yield required additional monitoring of streamflow below the confluence of the three branches in order to estimate the average annual recharge of the aquifer. This included the following:

- Streamflow monitoring accomplished with a simple staff gauge that would be observed weekly or monthly, coupled with several flow measurements per year.
- Monitoring need only be done during the dry season of June through October, since most water in the creeks would then be baseflow from groundwater.
- Several years of streamflow monitoring would improve the estimate of groundwater recharge because recharge varies with weather.
- Monitor water elevations at various locations in the aquifer, with up to two or three wells, perhaps utilizing the City's un-pumped well.
- Monitoring of the aquifer should be done monthly until typical seasonal patterns are known, then cut back to quarterly or half-yearly.

Implementing the above measures will:

- Be helpful to well owners that may be concerned about a depleted well supply.
- Help water managers compare current and historical conditions.
- Improved understanding of the specific dependency of the Wildcat Creek on baseflow.
- Help define safe yield.
- Allow for more accurate estimates of the effects of new pumping if the City needs additional water rights.

A risk to wells were reviewed and determined to include on-site sewage disposal; hazardous chemicals; and a lack of monitoring water quality for private wells – including background concentrations of caffeine and methylene, which are inexpensive to detect – with testing occurring once every few years.

The report noted the 1994 Hart Crowser report for the capture zone analysis, and although state-of-the-art methods were used to determine the zones, it was noted in their report that:

> It is important to recognize that these modeled capture zones are subject to uncertainty…The uncertainty is unavoidable because it is not possible to have perfect knowledge of the aquifer and its hydraulic properties. [p.10]

Due to this uncertainty, the report recommended the 10-year time-of-travel capture zone be enlarged by 50 percent to the west, and to the east it extends the zone to the railroad and highway to draw attention to the potential for spills from road vehicles or trains. This new area, designated the beneficial recharge area, is believed to sufficiently encompass the area that could contribute contaminants to the wells for the foreseeable future. The report also confirmed that till covers the entire Wildcat Creek aquifer and provides additional filtration for septic effluent, which delays the vertical movement of contaminants down the aquifer, allowing for more time to cleanup of accidental spills.

Regulatory alternatives were presented as options to address the protection and management of the aquifer, especially since the basin is without a practical alternative drinking water source. Although it was noted that all programs require detailed applications, considerable funding, and appear to be more complicated than needed for present management of the aquifer. The regulatory alternatives include:

- **Sole Source Aquifer Protection Program**: authorized by the Environmental Protection Agency, a sole source aquifer must supply at least 50% of the drinking water to persons living over the aquifer, and there can be no feasible alternative source of drinking water.
- **The Water Resources Act of 1971**: sole-source aquifers are singled out and referenced in several groundwater programs.
- **Regulation of Public Groundwaters Act, Chapter 90.44**: designated Groundwater Management Areas.
- **Special Protection Area – Department of Ecology**: designate groundwater that require special consideration or increased protection because of one or more unique characteristics, such as the groundwater that support a beneficial use or an ecological system requiring more stringent criteria than drinking water standards, including recharge areas and wellhead protection areas that are vulnerable to pollution because of hydrogeologic characteristics (and) sole source aquifer status by federal designation.
- **County Aquifer Protection Areas Act**: allows counties to create aquifer protection areas to finance the protection, preservation, and rehabilitation of the subterranean water.
- **Critical Aquifer Recharge Areas – Growth Management Act (GMA)**: the GMA requires all counties and cities, even those not planning under the Act, to designate and protect critical aquifer areas, among which are critical recharge areas defined as "areas where a critical recharging effect on aquifers used for portable water."
- **Chapter 36.70 and 35.63 RCW for Non-GMA Counties and Cities**: the land use eleventh for counties and cities not planning under the GMA, must include a land use element which shall provide for protection of the quality and quantity of groundwater used for the public water supplies.
- **Consistency of Development Regulations with Comprehensive Plan:** Beginning July 1, 1992, the development regulations of each city and county that does not plan under RCW 36.70A.040 [The Growth Management Act] shall not be inconsistent with the city's or county's comprehensive

plan. For the purposes of this section, "development regulations" has the same meaning as set forth in RCW 36.70A.030. (RCW 36.70.545 and RCW 35.63.125)

The results of this study provided the following recommendations:

A. Joint County – City Recommendations

1. Establish the Wildcat Creek Aquifer Management Area by inter-local agreement.
    - Purpose: To coordinate risk management and other actions to ensure the long-term benefits to the economy and to public health and safety provided by the Wildcat Creek Aquifer.
    - Management Principles: To ensure a margin of safety, manage the aquifer in accordance with the following principles:
        - Maximize recharge to the aquifer.
        - Minimize the transmission of contaminants to the aquifer.
        - Monitor well water and measure streamflows to learn more about the aquifer's hydrogeology, groundwater conditions, and safe yield.
        - Regulate land use in a manner that is clear, fair, and assures that groundwater will be protected.
        - Manage the aquifer comprehensively through compatible city and county policies, actions, and ordinances.
    - Responsibility:
        - Designate staff with responsibility for each action listed under (e) below.
        - Designate lead officials from each jurisdiction to oversee staff.
        - Publish an annual report on aquifer management.
        - Funding: Where appropriate, apply jointly for funding to carry out the management purposes of the Management Area.
    - Actions:
        - Update the list of potential point-source contamination sites within aquifer boundaries. Include sites on surrounding hillsides from which surface runoff could carry hazardous contaminates to the aquifer.
        - Monitor individual wells in the RR and R2 zones for quality. If water quality tests show a problem with a well, work with the landowner to correct the problem; the emphasis should be on assistance, not penalty.
        - Measure streamflow below the confluence of the three branches of Wildcat Creek and measure water levels in several wells to learn more about groundwater movement and quantity.
        - Review and coordinate spill-response plans(s) for accidental spills along transportation corridors within the Wildcat Creek Aquifer Management Area. Include Fire District 12 in this action.
        - Educate the public about the do's and don'ts of living above their water supply.
        - Adopt by reference the Low Impact Development Technical Guidance Manual for on-site development and surface water management.

- Review and, where appropriate, revise the zoning ordinances of both jurisdictions to prevent the location above the aquifer of land uses and activities that would introduce risks that could not be eliminated by development conditions and operating practices. This would include a review of a zoning district reclassification of general development five-acre (G-5) for any property currently zoned industrial (1-1 or 1-2).

2. Under the Community Plan Coordination Element of the Grays Harbor County Comprehensive Plan, review and, if necessary, revise the City and County plans for the area. In accordance with Policy (9), designate an urban services area for the City of McCleary.

B. Recommendations for Grays Harbor County

1. Adopt an ordinance that (1) affirms the Grays Harbor County Comprehensive Plan's policy basis for zoning in the Wildcat Creek Valley and (2) cancels the development moratorium upon the completion of the adoption process for amending Grays Harbor County Code 17.56.180 governing critical areas.
2. Designate the City of McCleary's wellhead 1-year capture zone, the 5-year capture zone, and the 10-year capture zone, as delineated by Pacific Groundwater Group in this report, as a critical aquifer recharge area.
3. Amend the Grays Harbor County Code for critical areas, Title 17, to define the Wildcat Creek Aquifer as a specific area.
4. Set forth requirements and review responsibilities for development activities, including rezones and subdivisions, located within the Wildcat Creek Aquifer.
5. Set forth requirements for development activities, including rezones and subdivisions, located within a Wildcat Creek critical aquifer recharge area, including a wellhead and wellhead time-of-travel protection plan. Specify that purveyors shall review the proposals and that the Grays Harbor County Environmental Health Division shall determine whether the proposal would provide a reasonable margin of safety for the critical aquifer recharge area; and further, that the if proposal does not, the proposal shall be (a) required to be revised to increase the margin of safety, including a reduction in lot density, or (b) shall be denied based upon evidence that the proposal represents a probable significant adverse impact to the critical aquifer recharge area.

C. Recommendations for the City of McCleary

1. Investigate the feasibility of establishing a back-up wellfield.
2. Designate the City portion of the wellhead protection area for the City wells as a critical aquifer recharge area.
3. Revise the City's wellhead protection area to conform to the ten-year time-travel capture zone, based on the delineation by Pacific Groundwater Group.
4. Revise the City's Integrated Pest Management program to make it more workable.
5. Develop a monitoring program to determine whether on-site sewage systems located in the wellhead protection area on Lynch and Larson Roads are contributing contaminants to City wells.
6. Reconsider the existing industrial zoning above the aquifer.

7. Continue efforts to reduce per capita water consumption.

3 Basin Setting: Overview

The following describes historic trends in precipitation and temperature, including predicted future changes.

3.1 Basin Settings

3.1.1 Precipitation:

Groundwater in the basin originates from local precipitation dominated by rain. While some precipitation quickly returns to the atmosphere by evaporation and transpiration through plants, the remaining precipitation drains across the surface and runs off into streams and also recharges the Wildcat Creek Aquifer groundwater system through infiltration. Evaporation peaks in summer months, while surface water runoff and infiltration dominate in the winter. During a 7-month period, from October through April, 85 percent of annual precipitation occurs, with demand peaks during the remaining 5-month period of May through September.

3.1.1.1 Precipitation and Temperature in Grays Harbor County

Within Grays Harbor County, precipitation trends from 1895 to 2023 show an annual average precipitation of 95.54 inches with an increase of 0.14 inch per decade (+1.36 inch/Century). The greatest peak in precipitation occurred in year 1933, followed by 1997 (Figure 14). Temperatures are increasing in Grays Harbor County. The mean average temperature over this time period is 49.4F°, with an increase in 0.2 F° per decade (+1.5 F° /Century). The average annual temperature peak occurred in 2015 (Figure 15). Increases in average maximum temperature (+0.2 F° /Decade; +1.5F° /Century) and the average minimum temperature (+0.2 F° /Decade; +1.6 F° /Century) were observed between 1895 to 2022 (NOAA, 2023a).

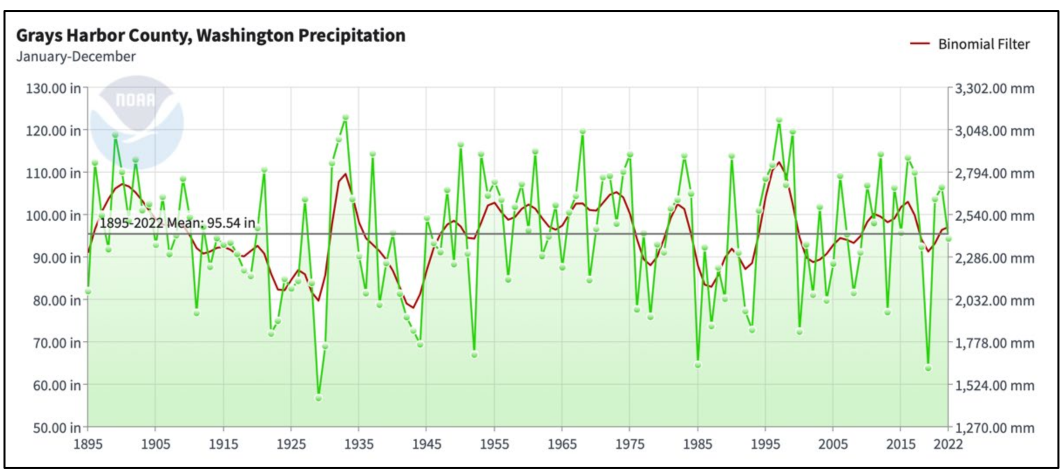

Figure 14. Annual precipitation in Grays Harbor County from 1985 to 2023

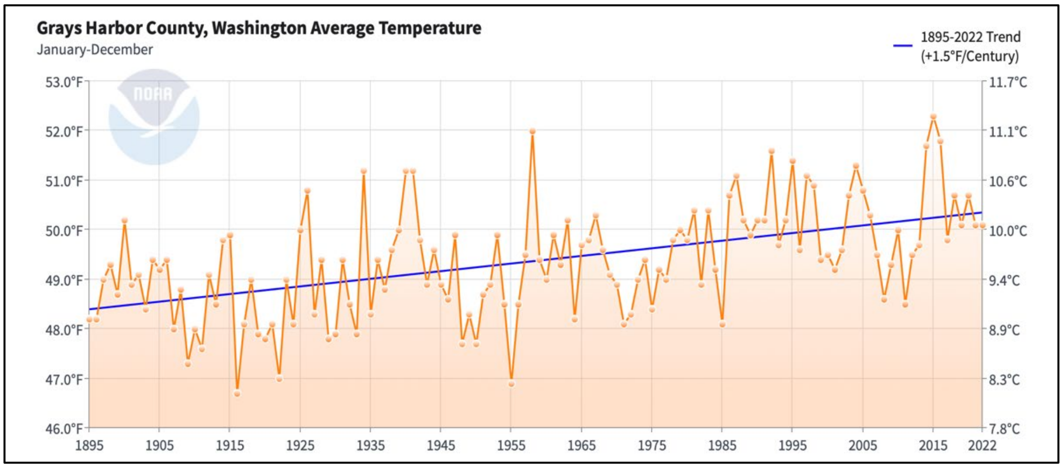

Figure 15. Mean annual temperature in Grays Harbor County from 1985 to 2022

3.1.1.2 Precipitation and Temperature in Mason County

Within Mason County, precipitation trends from 1895 to 2022 show and annual average precipitation of 88.6, with an increase of 0.51 inch per decade (+5.12 inch/Century). The greatest peak in precipitation occurred in year 1997 followed by 1999 (Figure 16). Temperatures are increasing in Mason County. The mean average temperature over this time period is 48.5F°, with an increase in 0.1F° per decade (+1.4F° /Century). The average annual temperature peak occurred in 2015 (Figure 17). Increases in average maximum temperature (+0.1 F° /Decade; +1.2F° /Century) and the average minimum temperature (+0.2 F° /Decade; +1.5F° /Century) were also observed between 1895 to 2022 (NOAA, 2023a).

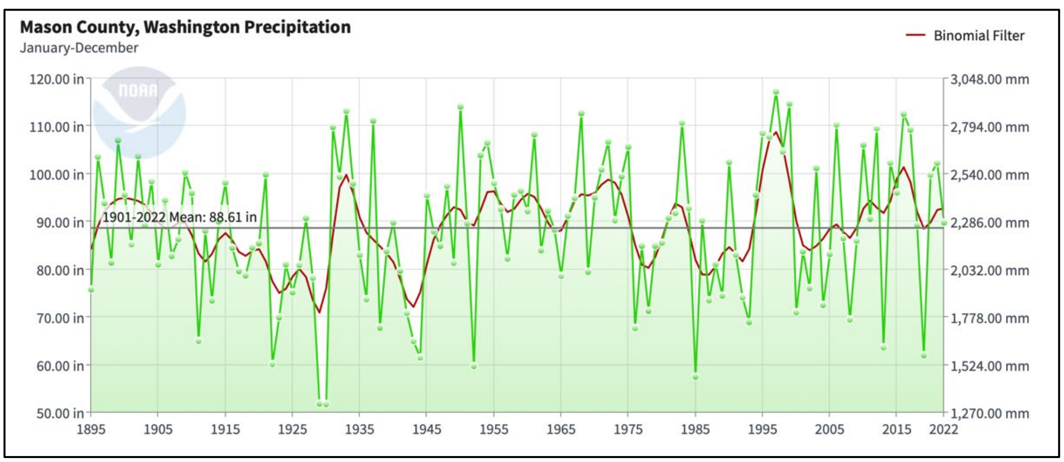

Figure 16. Annual precipitation in Mason County between 1895 and 2023

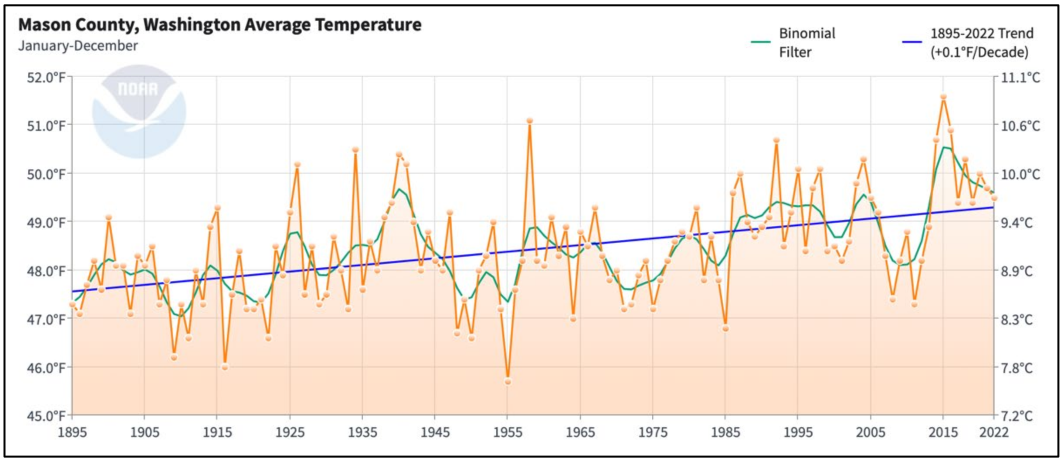

Figure 17. Mean annual temperature in Mason County from 1985 to 2022

3.1.1.3 Precipitation and Temperature in Elma

The closest weather station to McCleary, with significant historical weather observations, is located in Elma, which is approximately 9.5 miles southwest of McCleary and 220 feet lower in elevation. Average annual precipitation was estimated as 68.44 inches, with a maximum of 93.24 inches, which occurred in 1997, and a minimum of 42.36 inches in 1943[7] (NOAA, 2023b). An increasing trend in precipitation was observed between 1940 to 2022 with an increase of 0.14 inches per year. Temperature also increased during this time period as minimum and maximum trends in temperature increased slightly over time (Figure 18).

[7] The Simple Arithmetic Mean Method was used to estimate missing average precipitation station data. Supplemental station data were obtained from Aberdeen and Olympia. Min and Max precipitation were determined using Elma Station data.

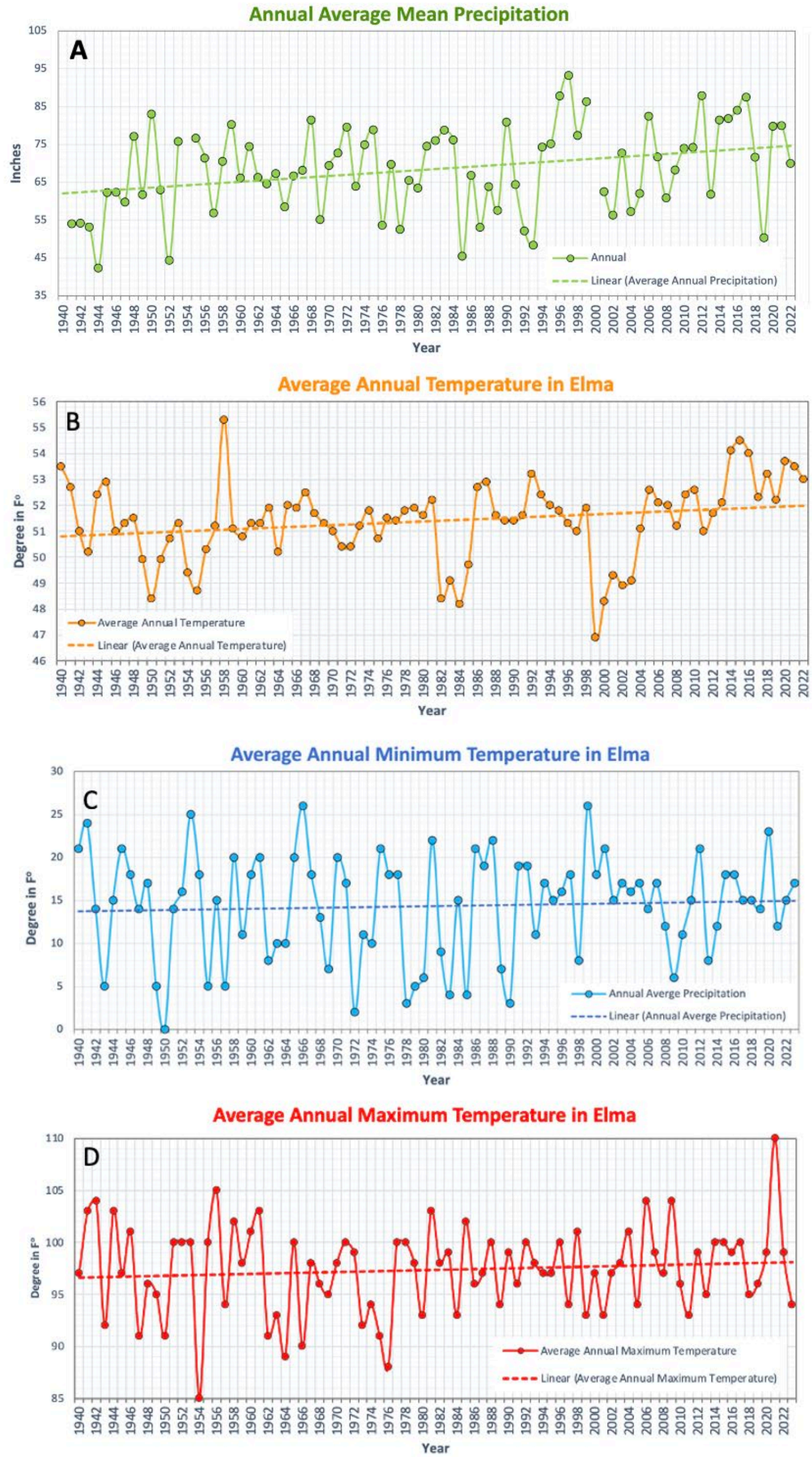

Figure 18. (A) Annual average precipitation,(B) average temperature, (C) average minimum temperature, and (D) average maximum temperature in Elma, WA from 1940 to 2022

In the city of Elma, the wettest months of the year are November through February, which account for 58% of precipitation, while June, July, and August are the driest months. Figure 19 shows the percent of total average annual precipitation by month between 1941 and 2022.

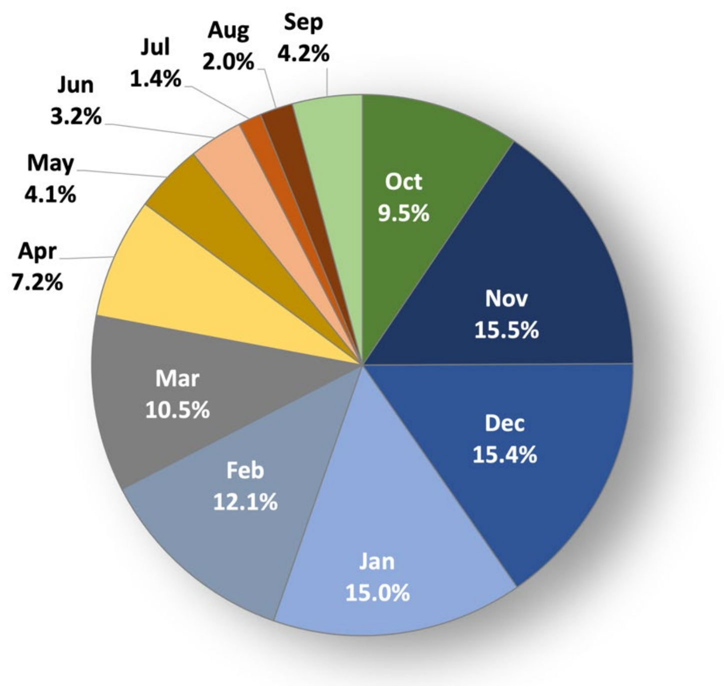

Figure 19. Percent of total average annual precipitation by month for the city of Elma, WA from 1941 to 2022

3.1.1.4 Predicted Changes in Regional Precipitation

Changes in precipitation, provided by the Washington the University of Washington's Climate Impact Group (2023) indicate an increase in precipitation by up to 19.7 percent in year 2099, under a higher temperature scenario (RCP 8.5), compared to historical baseline years (1980-2009) (Table 2).

GRAYS HARBOR COUNTY PERCENT CHANGE IN TOTAL ANNUAL PRECIPITATION	MODEL MEDIAN	MODEL RANGE (10TH TO 90TH PERCENTILE)
1980-2009		
Historical Baseline	88 inches	63 to 92 inches
2020-2049		
Higher Scenario (RCP 8.5)	2.6 %	-0.5 to 8.7 %
2030-2059		
Higher Scenario (RCP 8.5)	4.8 %	-1.3 to 11.3 %
2040-2069		
Higher Scenario (RCP 8.5)	5.2 %	-0.2 to 14.1 %
2050-2079		
Higher Scenario (RCP 8.5)	6.8 %	1.5 to 13.0 %
2060-2089		
Higher Scenario (RCP 8.5)	7.0 %	2.8 to 17.8 %
2070-2099		
Higher Scenario (RCP 8.5)	7.9 %	2.9 to 19.7 %

Table 2. Predicted changes in precipitation under higher climate scenario (RCP 8.5) for Grays Harbor County.

3.1.1.5 Spectral Moisture Index within and surrounding the Wildcat Creek Aquifer

Using spectral imagery from Sentinal-2, and processed in GIS, the normalized difference moisture index (NDMI) was calculated to spatially observe vegetation and water content, which is useful for monitoring water stress. The NDMI is calculated as a ration between the Near Infrared (NIR) and the shortwave infrared (SWIR). The equation to compute the NDMW is:

$$\frac{NIR - SWIR}{NIR + SWIR}$$

The NDMI range in value from -1 to 1, with blue indicating wet conditions and red corresponding to barren soil. Mid-range to red color indicates water stress, while shades of light to dark blue indicate high canopy without water stress.

Sentinal-2 began operating in 2015, and is a European wide-swath, high resolution, multi-spectral imaging mission, which include twin satellites flying in the same orbit (European Space Agency, 2023). Using these data, and for comparison purposes, five images during the month of July (2017, 2018, 2019) and August (2021, 2022) were obtained for the NDMI analysis, as these images were without cloud cover and timestamped within the same season. Results were compared to seasonal precipitation and seasonal temperatures during the period of observation. Lack of precipitation did not appear to be a factor in dry conditions; however, average temperatures during the month of July show a similar pattern of water stress and increased spatial density. For example, the greatest density of red occurs in 2021, which also corresponds to the highest average July temperatures (Figure 20).

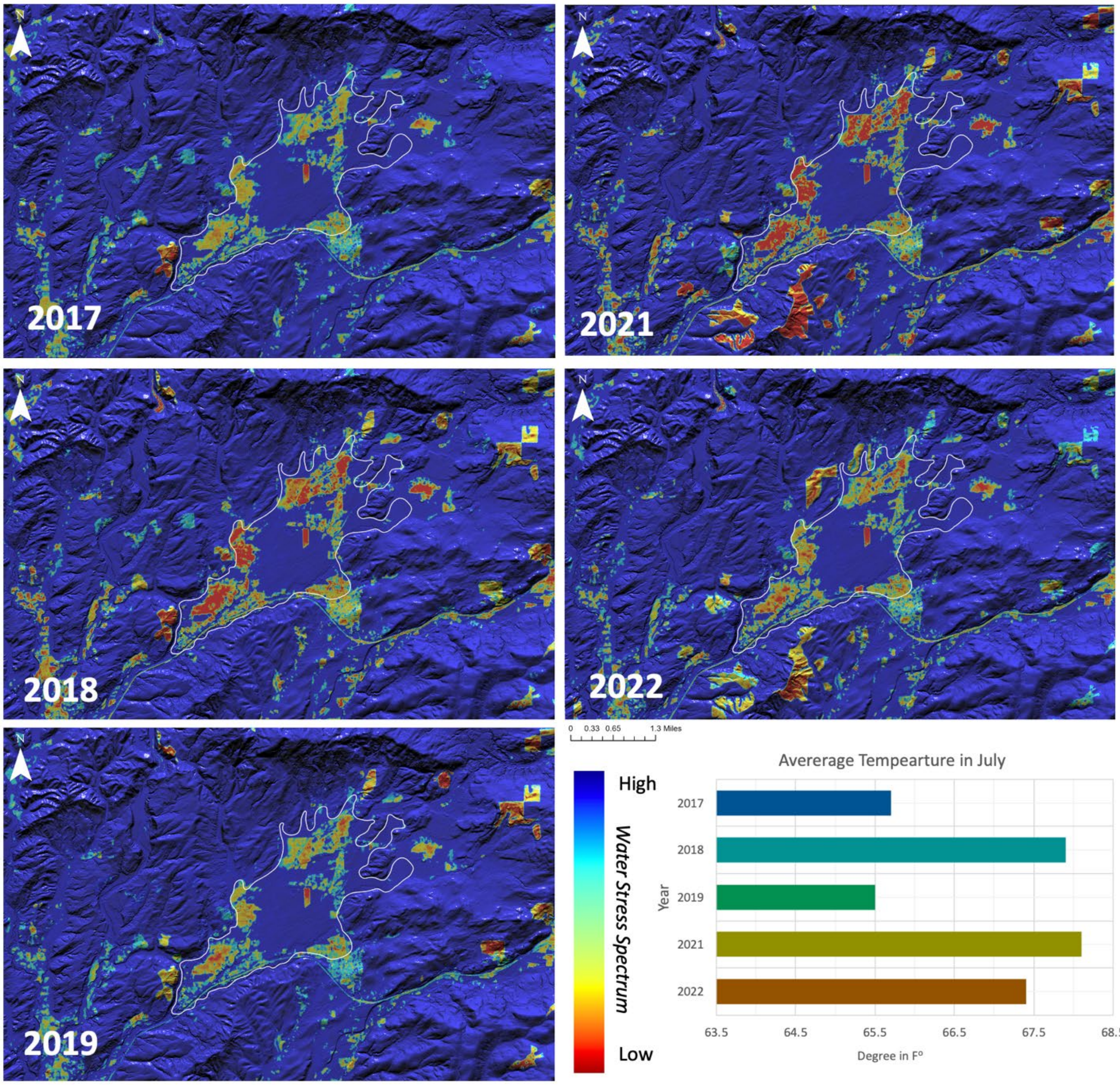

Figure 20. Results of NDMI and temperature profiles within and surrounding the Wildcat Creek Aquifer (white boarder). The NDMI images were taken in July (2017, 2018, 2019) and August (2021, 2022). Comparison average temperatures in July by year correspond to greater water stress observed on the spectral images, with respect to the given year. Water stress increases from the midpoint to red, while shades of light to dark blue indicate high canopy and low water stress.

3.2 Basin Setting: Hydrogeologic Conceptual Model

3.2.1 Regional Geologic and Structural Setting

The geologic history of the Wildcat Creek Aquifer extends beyond the boarders which encase it. This is a structurally isolated aquifer bounded by formations which span over a 40-million-year history. These formations, which isolate the aquifer, formed from the east and moved west, as seas were replaced with land due to uplift from the Cascade and Olympia Mountains, and the down warp of the Puget Trough. After these events occurred, which is represented in the basalt located northeast of the aquifer and the marine sediments to the southwest, two glacial periods along with weathering and erosion formed the aquifer utilized today (Figure 21).

Geologic Map of the Wildcat Creek Aquifer and Surrounding Formations

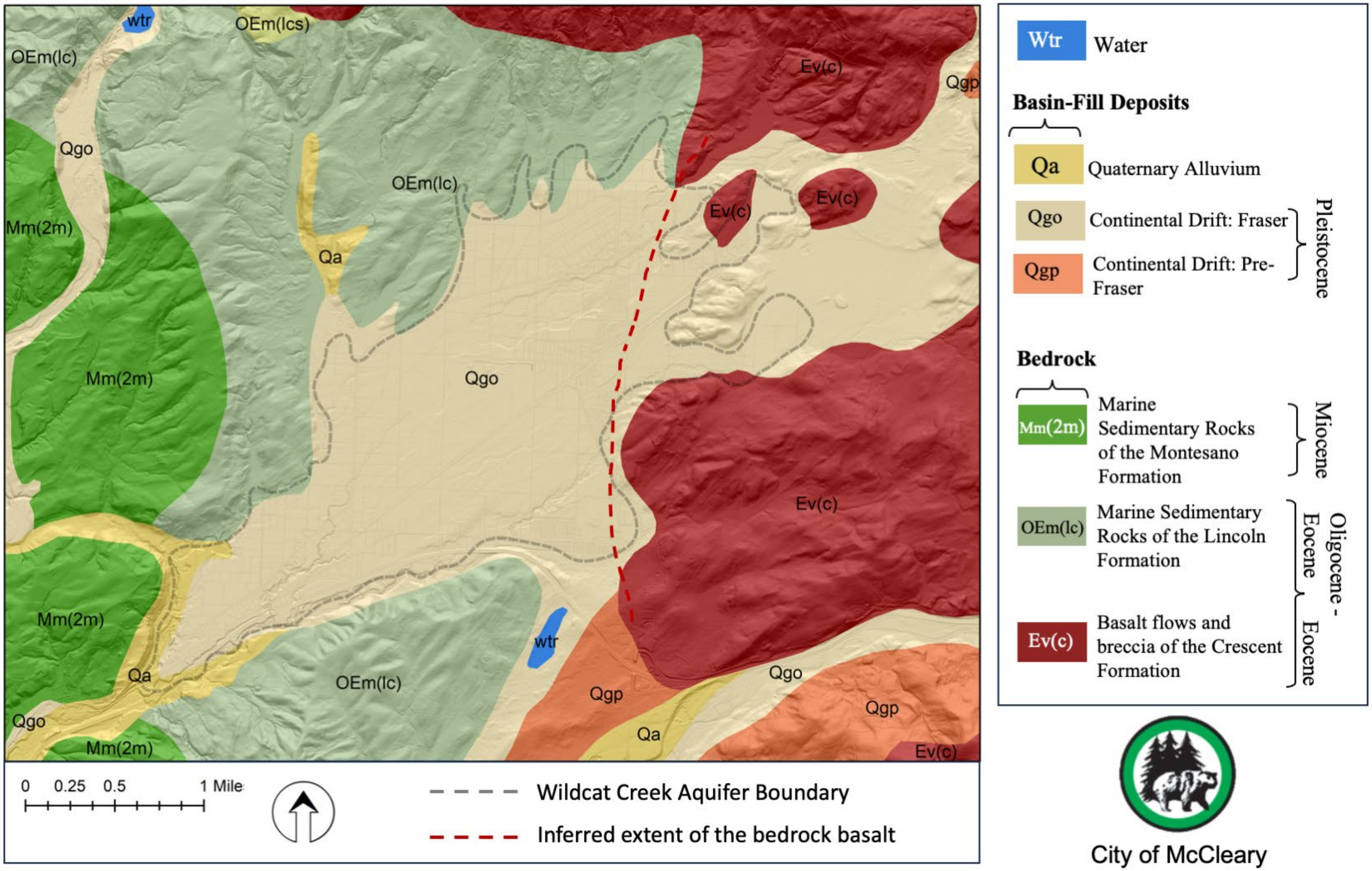

Figure 21. Geologic map of the Wildcat Creek Aquifer and surrounding topography. Data obtained from (Logan, 1987)

3.2.1.1 Geologic Formations/Stratigraphy

A geologic description, obtained from Logan (1987) of the Wildcat Creek Aquifer and the surrounding topography is described below. The following presents each formation in order of emplacement and stratigraphy.

3.2.1.1.1 Crescent Formation

The Crescent Formation, igneous in origin, is the oldest unit that forms the topographic highs to the east, and is of the Eocene epoch (60 to 40 million years ago). Well reports in this region show basalt flows and breccia, which underlie the eastern boundary of the Wildcat Creek Aquifer. The dotted red line in Figure 21 shows where the basalt boundary is estimated to exist, which was inferred from well logs and topography. The Crescent Formation was formed due to large-scale volcanism, which was deposited above and below shallow, warm seas.

3.2.1.1.2 Lincoln Creek Formation

The Lincoln Creek Formation formed during the Eocene-Oligocene epoch (65 to 24 million years ago), occurred at a time when shallow seas prevailed. Marine sedimentary rocks form the rocks which are topographic highs along the central portion of the aquifer. The Lincoln Creek Formation is often represented in driller well reports' as green shales with some clay, sand, and/or silt present.

3.2.1.1.3 Montesano Formation

The Montesano Formation formed during the Miocene epoch (25 to 10 million years ago) with shallow seas continuing to prevail from older Oligocene epoch until uplift of the ancestral Cascade Range occurred during the late Miocene. The Montesano Formation straddles the western portion of the aquifer and is somewhat indistinguishable from the Lincoln Formation in driller well reports, as it is reported as green in color with sand, silt, and gravels and is also mapped as marine sedimentary rocks.

3.2.1.2 Glaciation of the Pleistocene

Sediments within the Wildcat Creek Valley were derived from two glacial advances; the Double Bluff glacial period, which occurred 100,000 years ago and deposited advance outwash sediments, which was subsequently overlayed by glacial till that accumulated below the ice. This is apparent in the yellow hardpan description in driller well reports. Although previously assumed to be till derived from the most recent glacial advance, the yellowish weathered color - a sign of iron oxide- indicated the till was emplaced prior to the last glacial event (Arthur & Pacific Groundwater Group, 2008).

Glacial till, often described in well reports as hardpan, is composed of unsorted gravel deposits, which are firmly encased in a matrix of sand, silt, and clay. Glacial till is commonly described as yellow to grey in color and can be as hard as concrete. The ratio of gravel within the matrix is highly variable since its quantity within the till is dependent on its presents at the time glaciers overtook the area. Till covered areas are usually poorly drained, therefore are commonly heavily vegetated (Noble & Wallace, 1966).

The Vashon state of the Frasier glaciation also contributed to the development of the aquifer. Although this glacial event occurred 100,000 years after the Double Bluff, it deposited a thin veneer of advance and recessional outwash over sediments of the Double Bluff glacial period (Arthur & Pacific Groundwater Group, 2008).

3.2.1.3 Quaternary Alluvium

Alluvium accumulated through fluvial and weathering action. The alluvium is present on stretches of the Wildcat Creek, most predominantly on the southwest portion of the aquifer.

3.2.2 Basin Boundaries

The boundary of the basin generally follows the topography, with the aquifer bounded by basalts of the Crescent Formation to the northeast, and marine sedimentary rocks of the Lincoln Formation to the southwest. For the purpose of this project, the aquifer boundary was delineated based on topographic barriers (Figure 21).

3.2.3 Principal Aquifers and Aquitards

The principal aquifer of the Wildcat Creek Aquifer is the lower aquifer comprised of glacial outwash, which mostly underlies a confining layer of till. Till acts as a semi-confined to confined aquifer (aquitard) and is often close to the ground surface, with the exception of a few locations where the till is not present.

3.3 Aquifer and Surface Water Conditions

3.3.1.1 Aquifer Water Quality

Groundwater quality in the basin is generally of good quality, with some residents describing their well water as superior; however, some residents also reported degraded water, described as yellowish in color, which discolors sinks and bathtubs. Well water which exhibit yellowish color is likely withdrawing water containing iron from the confined glacial till, which is laterally extensive and may occur as lenses within the aquifer. These lenses were first reported in the Hart Crower (1994) report and are shown in Figure 13. In 2008, the Horsley Witten Group conducted a nitrogen loading analysis and determined concentrations of nitrate-nitrogen in groundwater are less than 0.1 milligrams per liter. Results also indicated that the confining layer is providing a significant level of protection to the lower aquifer, but risk of contamination from nitrates increase substantially in the surficial aquifer.

3.3.1.2 City of McCleary Water Quality

The city of McCleary tests for contamination in the pumped groundwater and at customer faucets, with the number of homes based on population. The tests include inorganic chemicals (lead and copper), disinfectant (free chlorine residual), disinfection byproducts (Hass and Trihalomethanes), asbestos, complete inorganics, volatile organics, pesticides, soil fumigants, gross alpha, and radium. Sampling is dependent upon requirements by the WA Department of Health; however, the City has received wavers for complete inorganics and volatile organics due to excellent results, and no evidence of 45 herbicides, pesticides, and soil fumigants (McCleary, 2019).

3.3.1.3 Wildcat Creek Water Quality

Surface water quality of the Wildcat Creek has been described as good, having chum and coho utilizing the stream for spawning and rearing. A report, *"Water Quality Studies of Wildcat Creek near McCleary, Washington"* (Musgrove, 1977) describes two significant fish kills that occurred in 1970 from toxic pollutants, with one kill totaling over 11,000 fish. At the time, prior to updates to effluent discharge to the creek, it was determined that both chemical and biological parameters were degrading aquatic habitat and reducing salmonoid fish population. Although current conditions have reduced the level of toxins entering the creek, some long-time residents observed a decrease in fish population from the 1970s to present time.

3.3.2 Surface Water and Recharge

Three branches of the Wildcat Creek traverse the aquifer and converge at the southwest corner of the basin. The drainage area of the watershed is approximately 22 square miles. Historic flow measurements are sparse and no current gaging or monitoring of streamflows are conducted on the creek. The following discusses available streamflow data previously collected or estimated.

In 1970, the USGS, conducted streamflow measurements on the East Fork of the Wildcat Creek (USGS Station ID: 12031890) over a period between January 1970 to January 1975. Flows ranged from 175 cfs to almost 600 cfs (Figure 22).

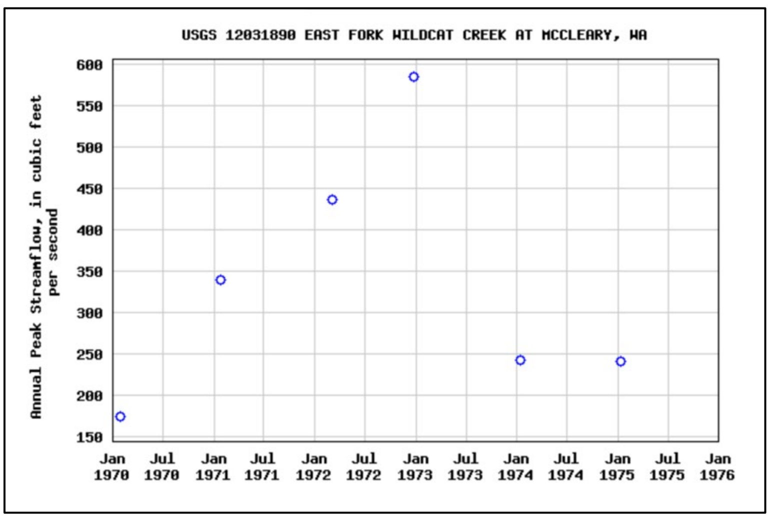

Figure 22. USGS Streamflow measurements on the East Fork of the Wildcat Creek from 1970 to 1975

In Melville (1970), streamflow observation and measurement were observed and described as follows:

> *"The stream flows across a long flat slab of concrete under the McCleary Highway bridge, just upstream from the entrance of the ditch carrying the plywood plant effluent. The slab is smooth but cobbled, and has a small amount of moss on it. On a flat section 20 feet wide, the surface flow went a distance of 25 feet in an average of 7 seconds. The average water depth was roughly 3.6 inches. At the end of the slab the flow free falls about 6*

inches, unrestricted. The estimated flow from this date [March 31, 1970] is 21 cfs."

The USGS StreamStats tool, which estimates drainage areas, and provides basin characteristics including flow statistics, was applied to determine features of the Wildcat Creek (Figure 23). The StreamStats estimated a drainage area of 21.76 square miles, a creek bankfull channel width is 46.6 ft, a bankfull channel depth of 2.19 feet, bankfull streamflow rate of 717 cfs, and a cross sectional area of 90 to 134 feet squared (USGS, 2023).

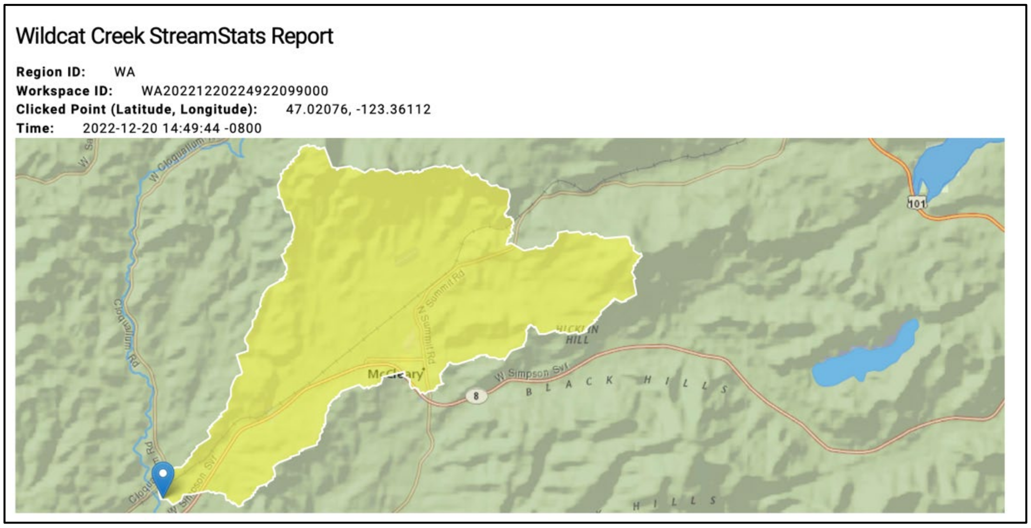

Figure 23. The Wildcat Creek watershed delineated by USGS StreamStats (USGS, 2023)

3.4 Basin Setting: Groundwater Conditions

3.4.1 Ecology Well Reports

The Washington Department of Ecology makes available a well report database (also known as well construction logs), which provides online resources to access local well logs. Not all well reports submitted to Ecology are available in the database and those which have associated map locations are located within a quarter of a mile of the well's actual location.

A total of 135 wells were located within the aquifer, and Figure 24 shows wells constructed in the aquifer over the period of record. The well reports obtained from the database required georeferencing respective addresses in a geographical information system (GIS). Although this allowed for greater spatial identification of well locations, not all well reports listed addresses. However, this approach allowed for evaluation of 77 wells, which are shown in Figure 25, with 57% of these wells constructed after 2004. The well logs were used to spatially delineate formation (unit) coverage, formation thickness, and the water level at the time of drilling.

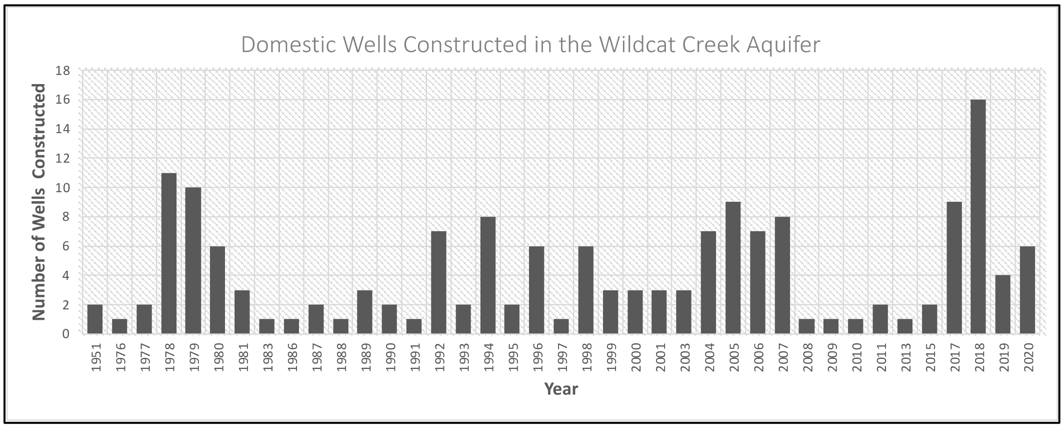

Figure 24. Number of domestic wells in Ecology's database constructed in the Wildcat Creek Aquifer

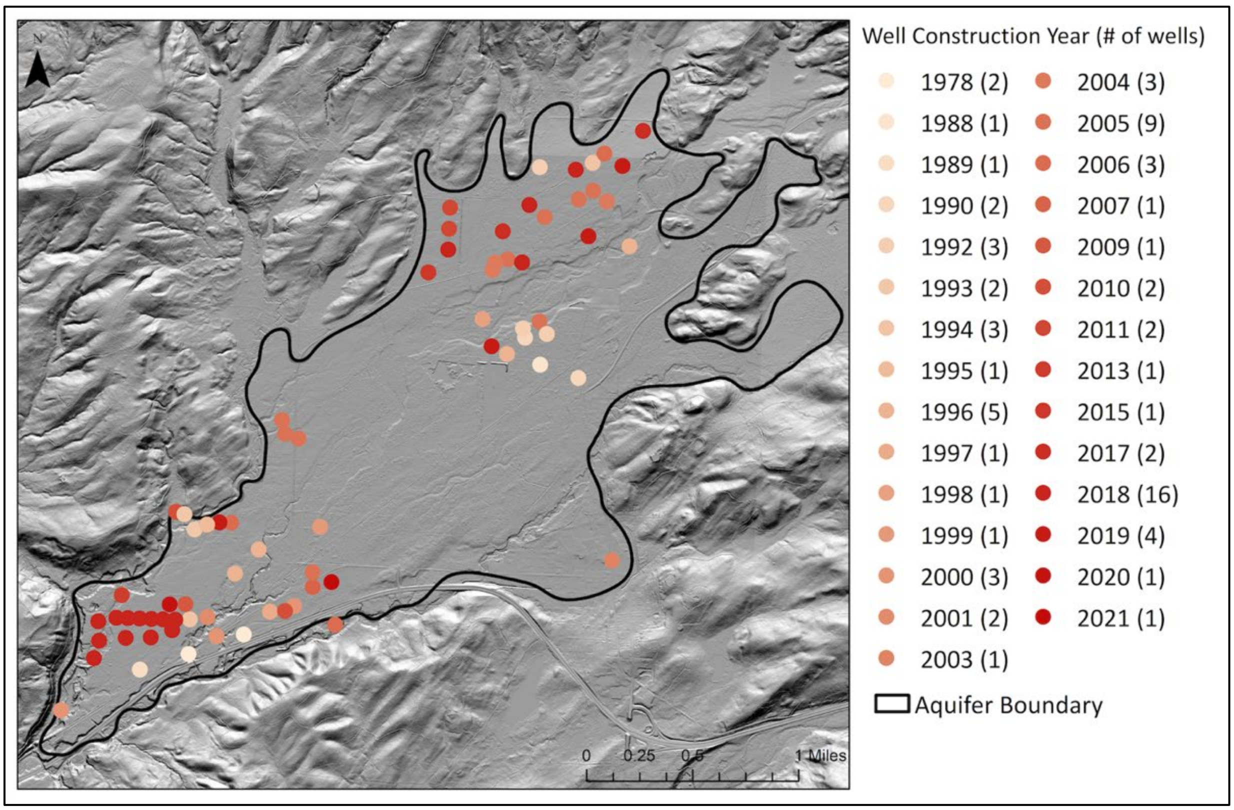

Figure 25. Location of the Department of Ecology well reports used in the study and the year of well construction.

Although the 77 well logs allowed for greater description of underground conditions and formation delineation, limitations exist in determining groundwater characteristics derived from Ecology well reports. These limitations include using static water level for wells drilled during different years, including different seasons, which does not capture annual and seasonal variability; drillers populated all the fields within the well report and may contain erroneous errors, including deciphering aquifer intervals. Well depths were assumed to be the base of the aquifer; however well drillers rarely drill to the bottom of an aquifer.

3.4.2 Wildcat Creek Aquifer

The hydrogeologic formation of the Wildcat Creek Aquifer comprises 5 distinct units, with 2 water bearing zones. The surficial unit is Aquifer 1, which is spatially disconnected and is a water bearing unit. Glacial till covers much of the basin and creates semi-confining to confining conditions throughout most of the underlying aquifer, which is Aquifer 2, comprised of advanced glacial outwash and is accessed by many of the domestic wells in the basin. Two bedrock formations partition the basin, with shale to the southwest, and basalt to the northeast.

3.4.2.1 Aquifer 1

A total of 18 wells delineated Aquifer 1. This formation was previously considered an insignificant water bearing unit originally described as a discontinuous thin veneer deposit with little water holding capacity. Although Aquifer 1 is not widespread in the basin, it reaches depths of up to 62 feet, and supports withdrawals for at least 12 wells (Figure 26).

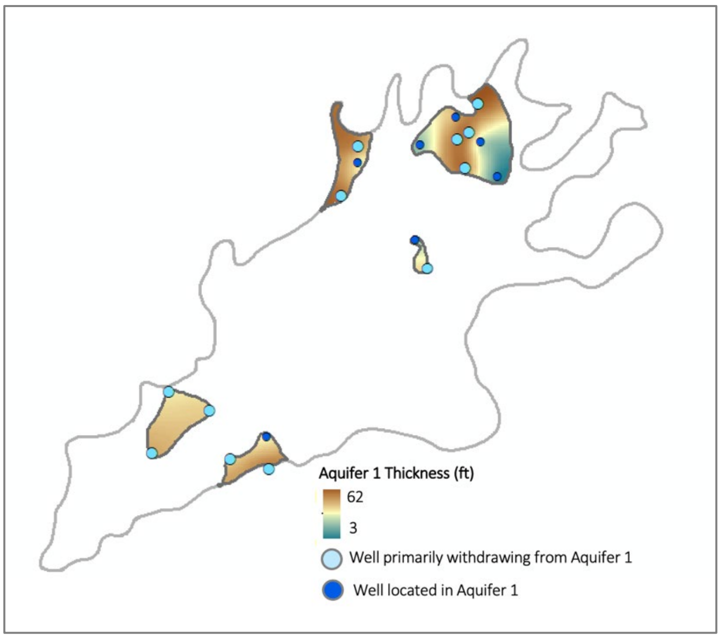

Figure 26. Domestic wells, thickness, and spatial coverage of Aquifer 1 in the Wildcat Creek Basin.

3.4.2.2 Till

Glacial till is laterally extensive throughout the basin. A total of 49 wells were drilled in the till, with 5 wells terminated in this unit, indicating the till maintains water bearing lenses at some locations. Thickness of the till range from surficial to 72 feet deep (Figure 27).

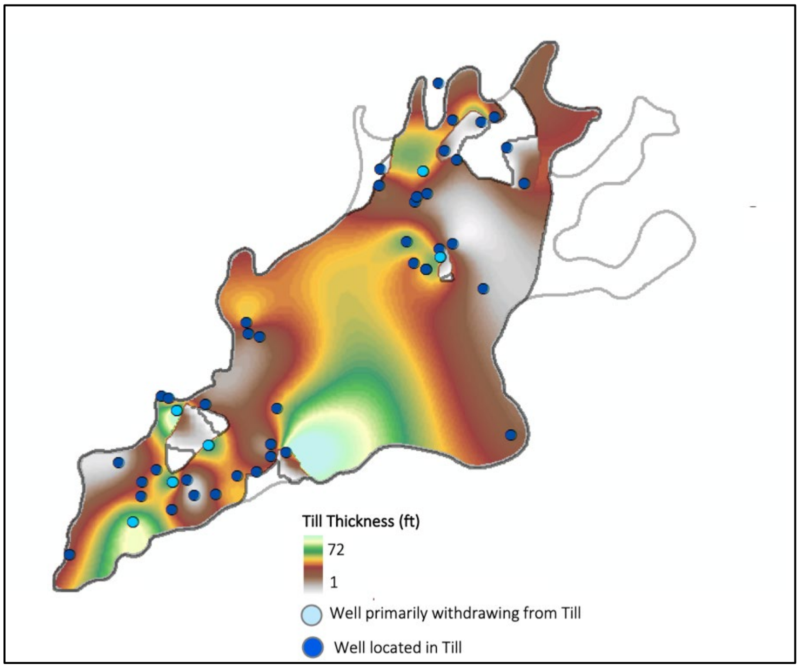

Figure 27. Domestic wells, thickness, and spatial coverage of Till in the Wildcat Creek Basin.

3.4.3 Aquifer 2

A total of 43 wells delineated Aquifer 2, with 25 wells primarily withdrawing groundwater from this unit, including the City wells. The thickness of Aquifer 2 ranges from 20 to 119 feet (Figure 28).

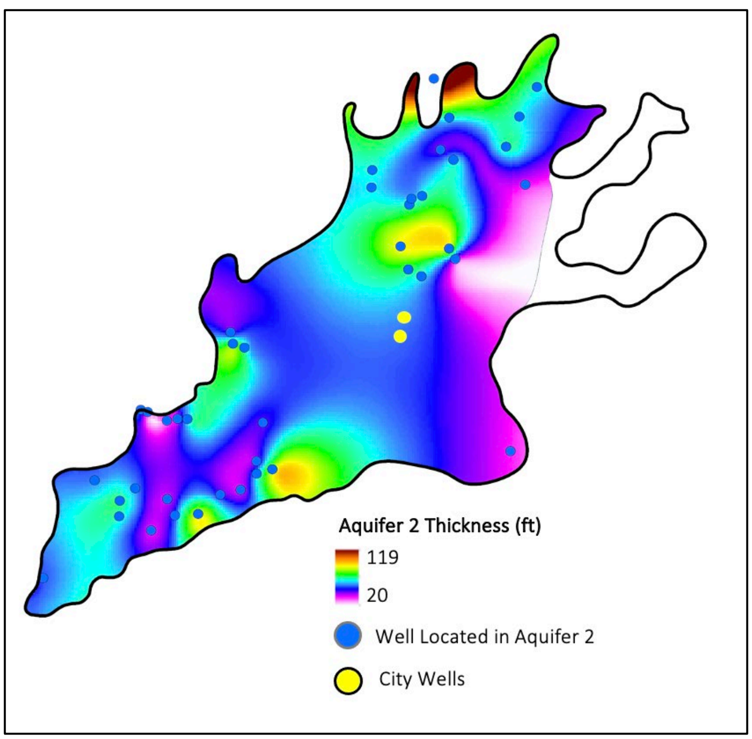

Figure 28. Domestic wells, thickness, and spatial coverage of Aquifer 2 in the Wildcat Creek Basin.

3.4.3.1 Shale

A total of 33 wells accessed and are terminated in the shale unit. The shale is 40 to almost 200 feet thick and potentially contain water bearing properties (Figure 29).

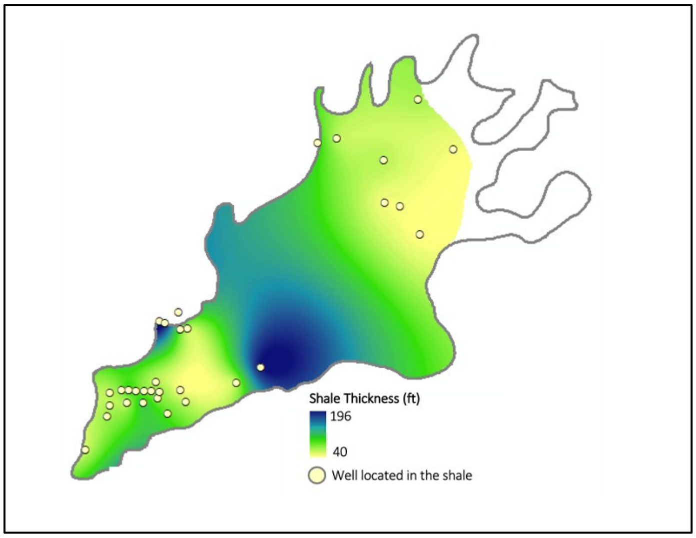

Figure 29. Domestic wells, thickness, and spatial coverage of Shale in the Wildcat Creek Basin.

3.4.3.2 Basalt

Three wells within the basalt unit were located on the northeastern corner of the basin. The depth to the bottom of the basalt ranges from 37 and 124 feet, with thicknesses 5 to 16 feet deep within 3 wells. The basalt is likely deeper and thicker in extent; however, only a few wells within the basalt provide information to estimate its characteristics and are unlikely drilled to the bottom of the formation (Figure 30).

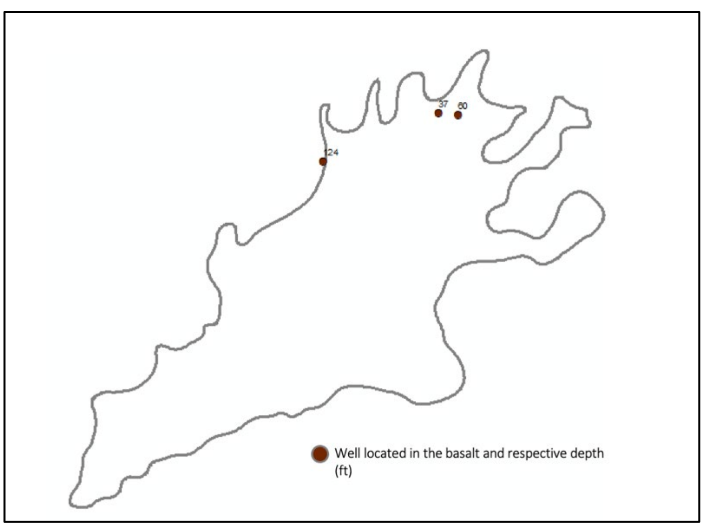

Figure 30. Wells located in the Basalt unit in the Wildcat Creek Aquifer

3.4.4 Static Water Level

Static water level (SWL) is the depth of water in feet below ground surface (ft bgs) in a well and recorded at the time of drilling or measured at a later date and has not been influenced by pumping. In an unconfined aquifer, such as the advanced glacial outwash of Aquifer 1, the SWL is the height of the water table. The SWL in a confined well, is the height of the potentiometric surface. This surface represents the height the water would reach, if not under pressure, such as the condition where till overlies Aquifer 2.

3.4.4.1 Static Water Level of the Basin

The average SWL for wells evaluated within the basin was estimated at 15 ft bgs. No artesian wells were identified, however minimum SWL equaled 2 ft bgs, while the deepest SWL occurred at 38 ft bgs. Figure 31 shows the SWL for all wells evaluated and subdivided by formation.

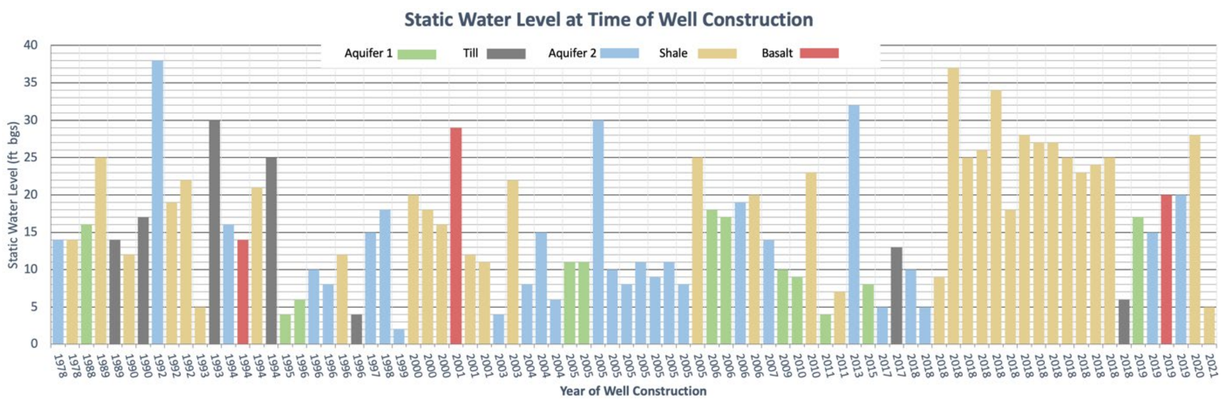

Figure 31. Static water levels of wells, by formation, in the Wildcat Creek Aquifer at the time of construction.

The following describes the SWL of the wells located within each formation, which was assumed as the primary source of groundwater for the well.

3.4.4.2 Static Water Level of Aquifer 1

Static Water level in Aquifer 1 shows an average, minimum, and maximum SWL of 11-, 4-, and 18 ft bgs respectively, with 12 wells withdrawing groundwater from this formation (Figure 32).

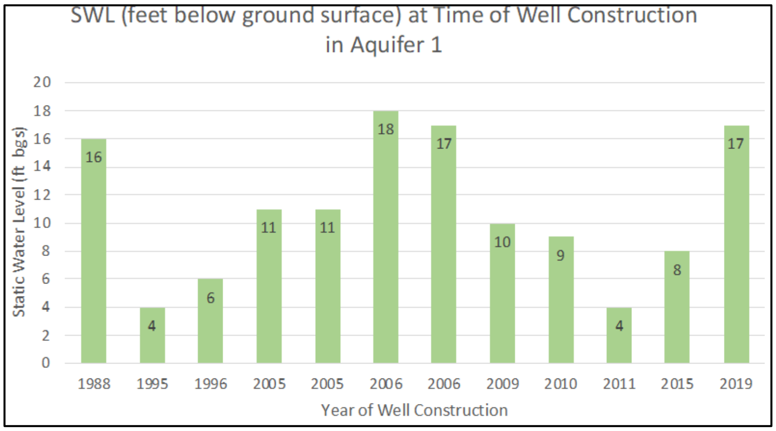

Figure 32. Static water level of wells accessing Aquifer 1.

3.4.4.3 Static Water Level in Till

Only wells 6 wells were identified as terminating in the semi-confined to confined till. The SWL in these wells have an average, minimum, and maximum SWL of 18-, 4-, and 32 ft bgs, respectively (Figure 33)

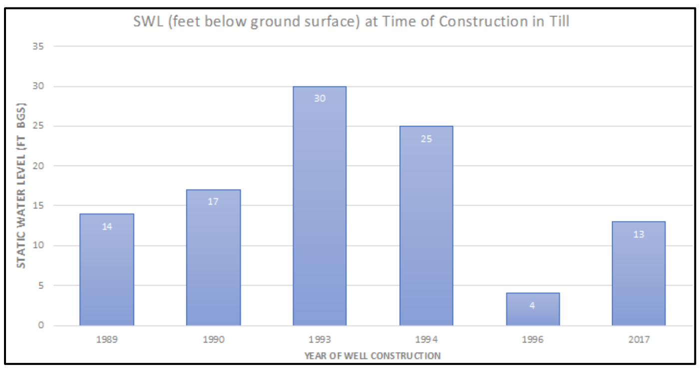

Figure 33. Static water level of wells withdrawing groundwater within the till of the Wildcat Creek Aquifer.

3.4.4.4 Static Water Level in Aquifer 2

In Aquifer 2 - the most prolific aquifer in the basin - 25 well logs (out of the 77 surveyed) access this aquifer. The SWL varied from 2 to 38 feet, with an average SWL of 12 feet (Figure 34).

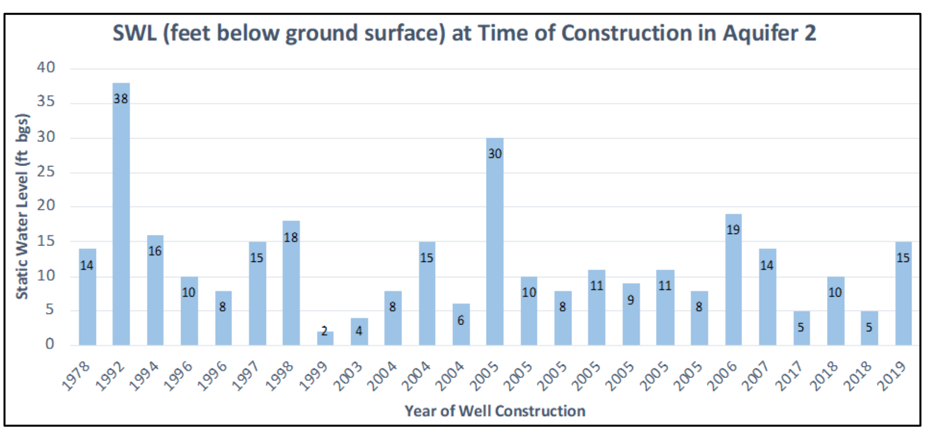

Figure 34. Static water level of wells withdrawing groundwater within the till of the Wildcat Creek Aquifer.

3.4.4.5 Static Water Level in Shale

Shale underlies Aquifer 2, and many wells access this formation. Although it is unclear the productivity of wells which utilize shale, 33 wells in the basin were completed within the shale. Static water level in the shale ranges from 5 to 37 ft bgs, with an average SWL of 20 ft bgs (Figure 35).

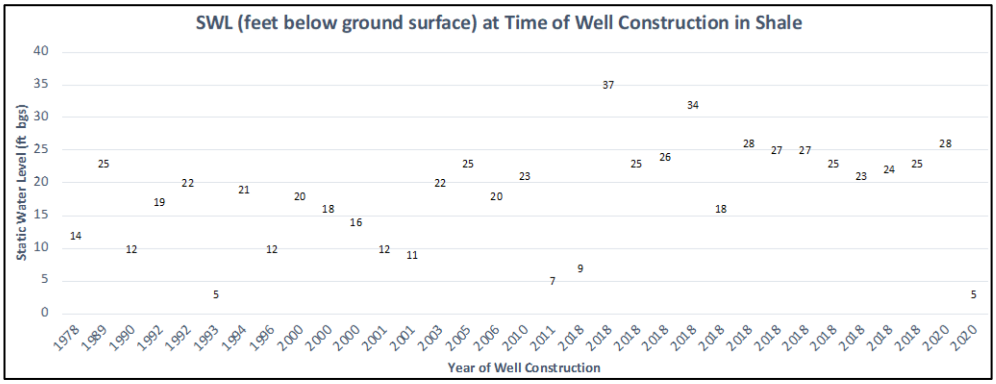

Figure 35. Static water level of wells withdrawing groundwater within the shale of the Wildcat Creek Aquifer.

3.4.5 Groundwater Elevation

Groundwater elevations were derived from static water level recorded in well reports (Figure 36). The SWL was interpolated across the aquifer then converted to elevation contours, which provided an indication of the direction of flow. The groundwater flow paths are similar to the Hart Crower (1994) report (Figure 13), in that groundwater flows towards the confluence of the basin; however, it is unlikely groundwater flow takes a direct path from high to low elevation (Figure 14)

Groundwater Elevation and Direction of Flow

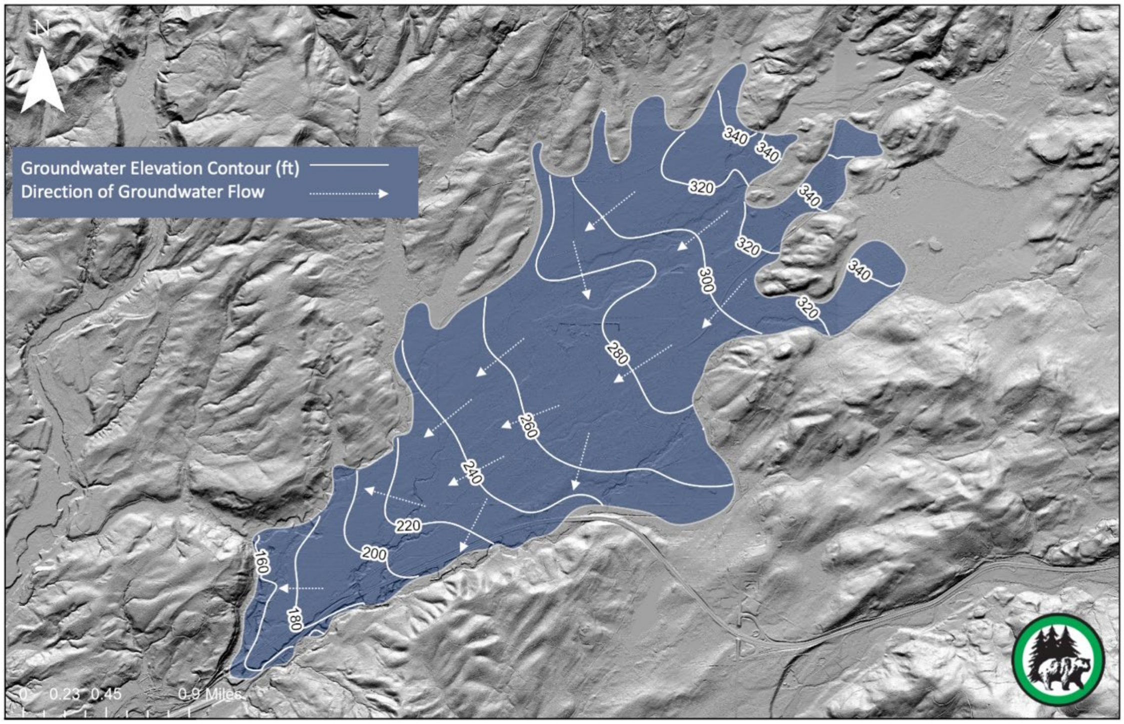

Figure 36. Groundwater elevation and direction of groundwater flow within the Wildcat Creek Aquifer.

3.5 Undesirable Results

3.5.1 Chronic Lowering of Groundwater Levels

Chronic lowering of groundwater does not appear to be occurring throughout the basin. Water levels measured in 5 wells in Fall and Spring (Figure 37), show changes of up to 10 feet with an average change of 3 feet (Table 3).

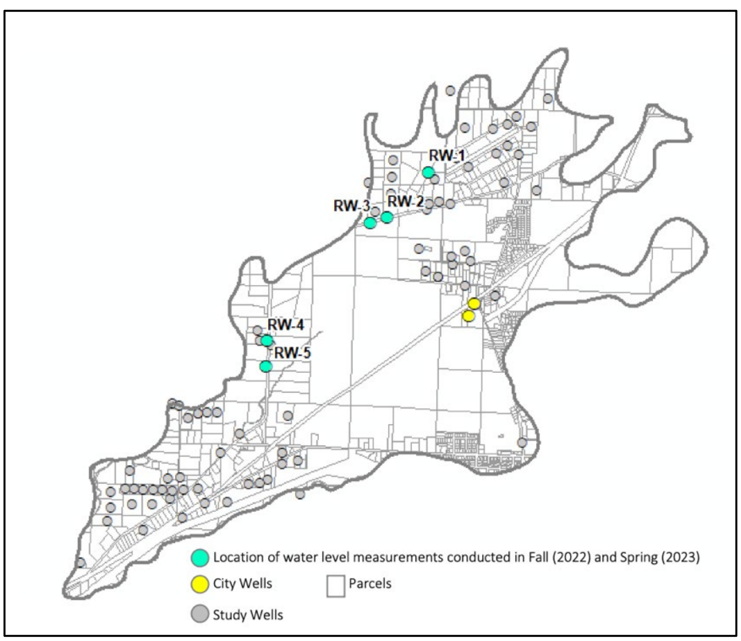

Figure 37. Location of water level measurements obtained in Fall of 2022 and Spring of 2023

Well	Date	Time	SWL (ft bgs)	Well Stickup (Ft)	DTW bls	Difference in Water Level
RW-1	11/3/22	14:20	17.10	1.30	15.80	**10.02**
RW-1	5/5/23	14:00	7.08	1.30	5.78	
RW-2	11/3/22	15:00	5.74	3.00	2.74	**0.74**
RW-2	5/11/23	12:50	5.00	3.00	2.00	
RW-3	11/3/22	14:45	5.83	1.00	4.83	**0.67**
RW-3	5/11/23	12:40	5.16	1.00	4.16	
RW-4	11/3/22	14:45	7.30	0.75	6.55	**0.43**
RW-4	5/11/23	12:00	6.87	0.75	6.12	
RW-5	9/17/22	10:50	12.54	1.33	11.21	**3.03**
RW-5	5/11/23	14:00	9.51	1.33	8.18	

Table 3. Water level measurement details for 5 residential wells. Measurements obtained Fall (2022) and Spring (2023).

3.5.1.1 Updates to the Conceptual Hydrogeolgic Model

The recharge area to city wells and capture zone was delineated by Hart Crowser (1994). Our current understanding of aquifer conditions provided an updated recharge area and thickness of the till underlying the capture zones. The recharge zone to the wells was updated based on topographic variations yet maintain similar geometry as the Hart Crowser Report. The new recharge area is shown in Figure 38.

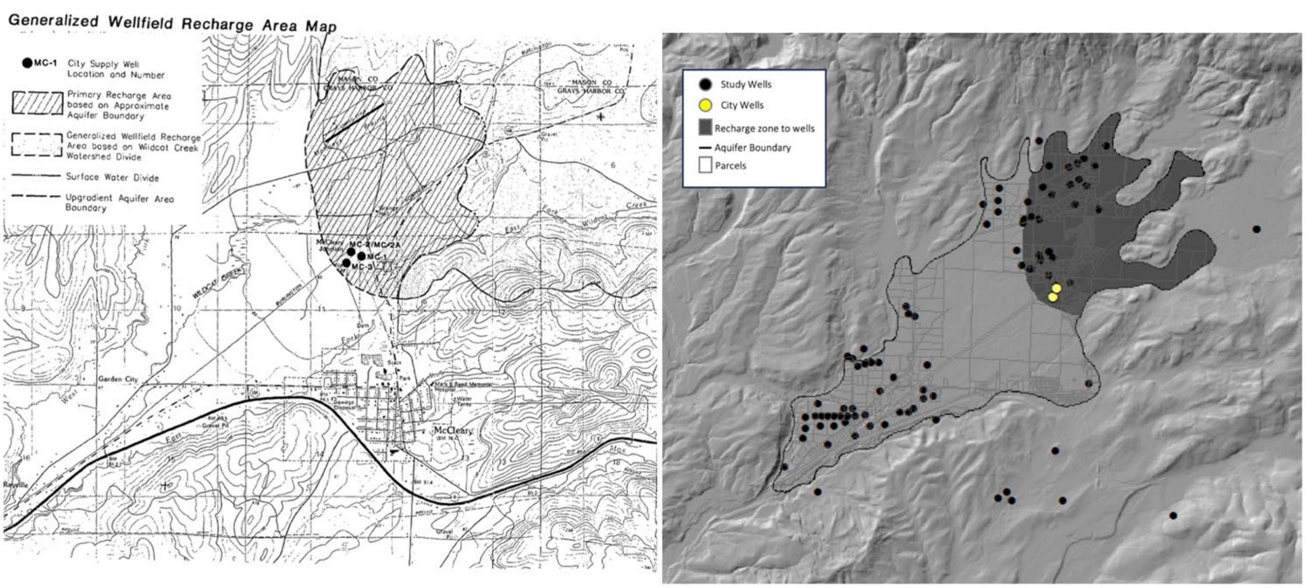

Figure 38. Updated recharge area to city wells. Hart Crowser (1994) on left, updated recharge area on right.

Till delays or prevents contaminants from entering the aquifer; however, in some locations, till is not present in some well logs shown in Figure 42. Precipitation at these locations likely recharge the aquifer directly and may be a conduit for contaminants to enter Aquifer 2.

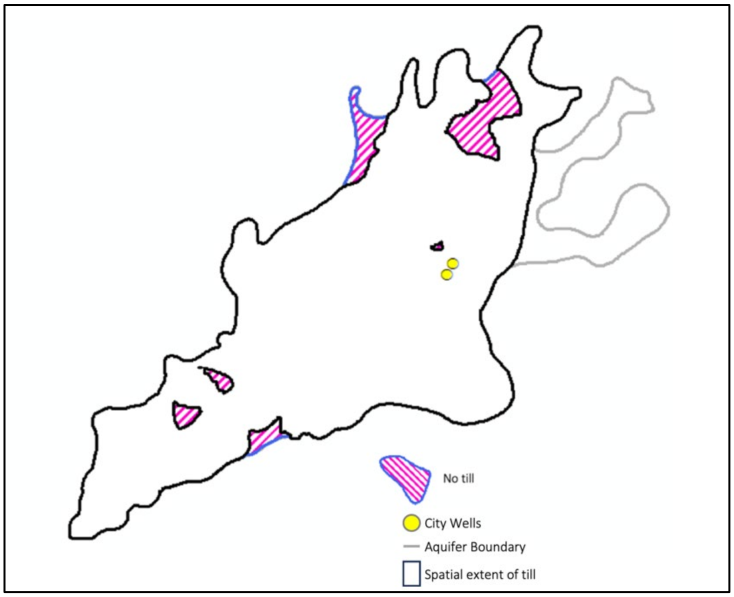

Figure 39. Spatial extent of till and the location of city wells, aquifer boundary, and where till is absent.

Although till often acts as a barrier to contaminants, till is not present throughout the area of recharge assumed to effect city wells. The thickness of the till in the recharge area ranges from 1 to 44 feet (Figure 40). Due to a lack of local wells in the northeast section of the recharge zone, delineation of aquifer properties could not be assessed.

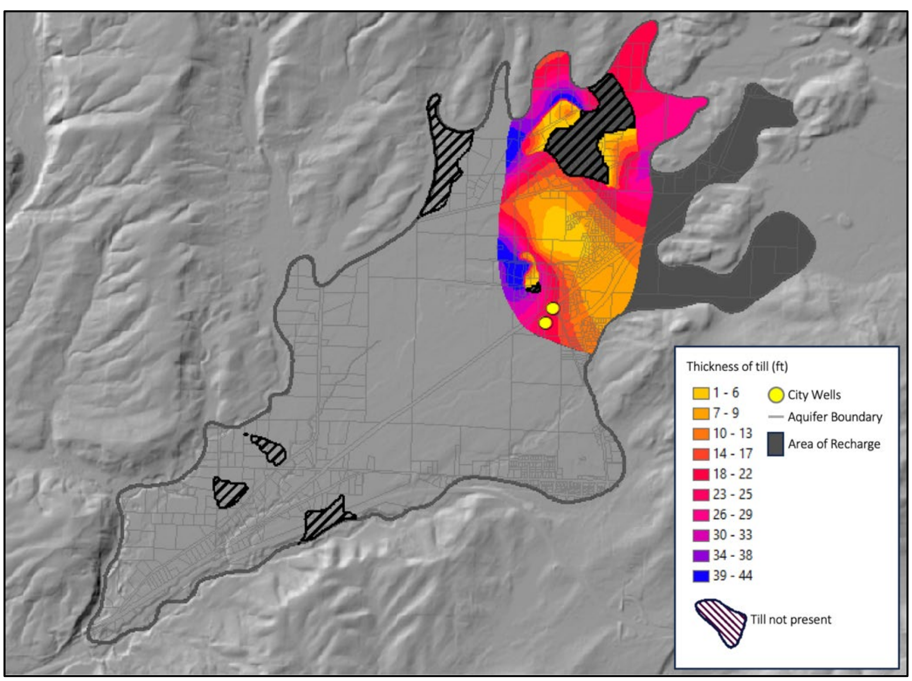

Figure 40. Location and thickness of till in the recharge zone.

Till is present throughout the 1-, 5-, and 10-year capture zones and range in thickness from 20 to 30 feet, with the exception of a portion of the 10-year zone undetermined due to a lack of data.

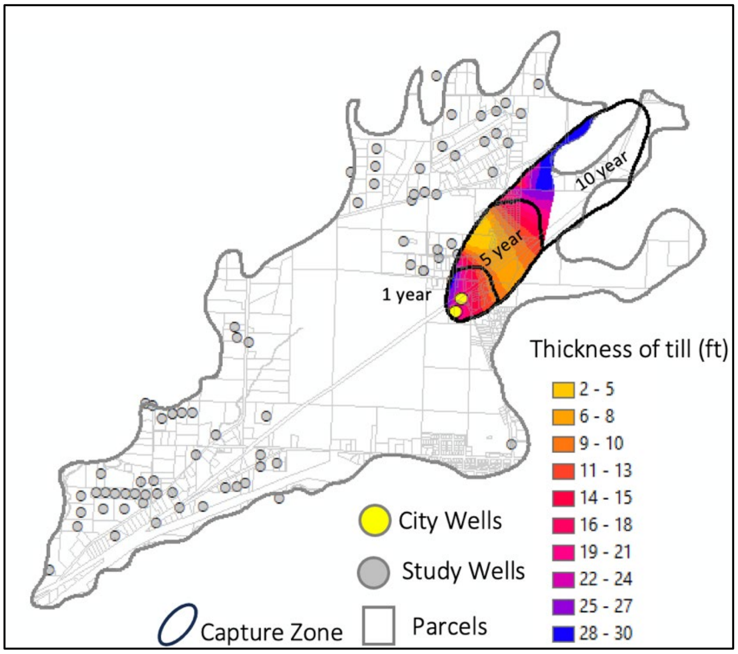

Figure 41. Location and thickness of till in the 1-,5-,10-year capture zone. Capture zones obtained from Hart Crowser (1994).

5 Management Actions and Projects

5.1 Sustainability and Undesired Results

To prevent loss of groundwater resources in the Wildcat Creek Aquifer requires maintaining sustainable groundwater supplies for all beneficial users of the aquifer, now and into the future. This can be accomplished by avoiding undesirable results defined as:

- Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon[8].
- Significant and unreasonable reduction of groundwater storage.
- Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair groundwater.
- Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

Potential causes of undesirable results for the chronic lowering of groundwater levels are groundwater pumping that exceeds the average sustainable yield in the basin or future changes in precipitation that reduce the amount of available water.

Sustainable yield is defined as how much water can be withdrawn from the aquifer, where and for how long, with acceptable physical, economic, environmental, social, cultural, institutional, and legal consequences (Walton & McLane, 2013). Sustainable yield can be estimated by modeling and simulating current and projected conditions under different scenarios.

5.2 Results and Discussion

Results of this work suggest groundwater levels do not fluctuate greatly compared to historic conditions, although seasonal variations were excluded due to the nature of available data, historic and predicted increases in precipitation suggest the basin will receive more water over time. Although the groundwater supply is stable, care needs to be taken when development of new homes increases the density of wells accessing lower permeable units, such as the shale, as well interference may cause local wells to lose capacity or run dry.

Historic analyses suggest the city wells are protected from contaminants due to the till acting as a barrier to recharge and the upward gradient, yet the results of this work show the till is discontinuous in the area of recharge, thereby increasing the likelihood contaminants may reach city wells in the lower aquifer where till is absent.

[8] Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

Although limited streamflow data on the Wildcat Creek exist, concerns over streamflows were raised by several residents in the area, as many believed the creek has lost volume over the past few decades, and fish population is less robust than previously witnessed. Additionally, consumptive groundwater withdrawals in the basin are likely to capture water that would otherwise discharge to Wildcat Creek.

To achieve sustainability for the Wildcat Creek Aquifer requires collecting additional groundwater data, streamflow measurements, and evaluation of ordinances and infrastructure. Aquifer sustainability can be defined as the amount of water that can be extracted from an aquifer under a given set of operating conditions, while meeting community-defined performance metrics. This will also evolve as policy goals change, and an as our understanding of groundwater conditions and technology increase (Sharp, 2016). By filling data gaps, this will allow for modeling aquifer parameters and management scenarios to determine the extent withdrawals are acceptable.

Aquifer management areas should be designed to prevent degradation of groundwater quality and quantity. The following proposes designating locations throughout the aquifer as most vulnerable to contamination or maintain high impact potential due to land use changes.

5.2.1 Till

The Hart Crowser (1994) and the Horsley Witten Group recommended constraining certain activities within the recharge area (Figure 38) and capture zones (Figure 41) to reduce potential contamination. These recommendations can be further refined to areas where till does not underlie Aquifer 1. Precautions should be taken near city wells to prevent contaminants from entering Aquifer 2, since the wells are located downgradient from an exposed portion of the aquifer (Figure 42), thereby increasing the likelihood of contaminants leaching into public water supply.

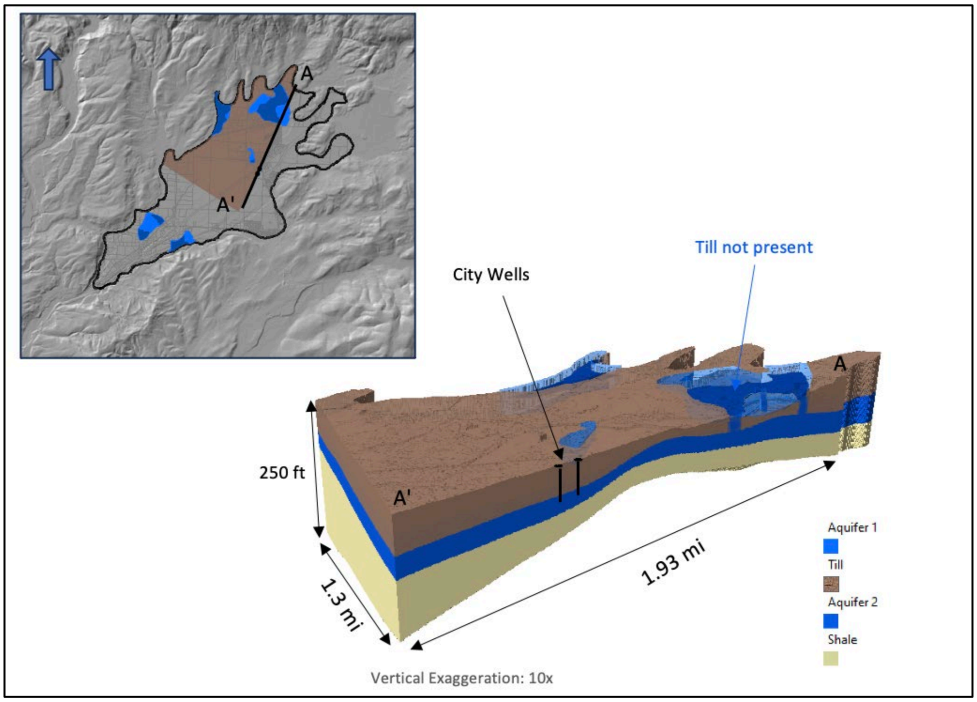

Figure 42. Geologic cross section adjacent to city wells

On the northwest section of the aquifer, standing water within private property was reported as a common occurrence. This condition likely occurs in areas where either till is close to the surface, which increases runoff, or where upward hydraulic gradients exist where till is not present. Timber harvesting can also impact surface flows. Harvesting mature trees can lead to a decrease in evaporation and an increase in peak flows or more rapid drainage and higher fluctuations between peak flows. Harvesting timber within the central portion of the aquifer (Figure 43) should be investigated, prior to tree removal, for the likelihood of downgradient alterations in water conditions, which could increase standing water in unwanted locations.

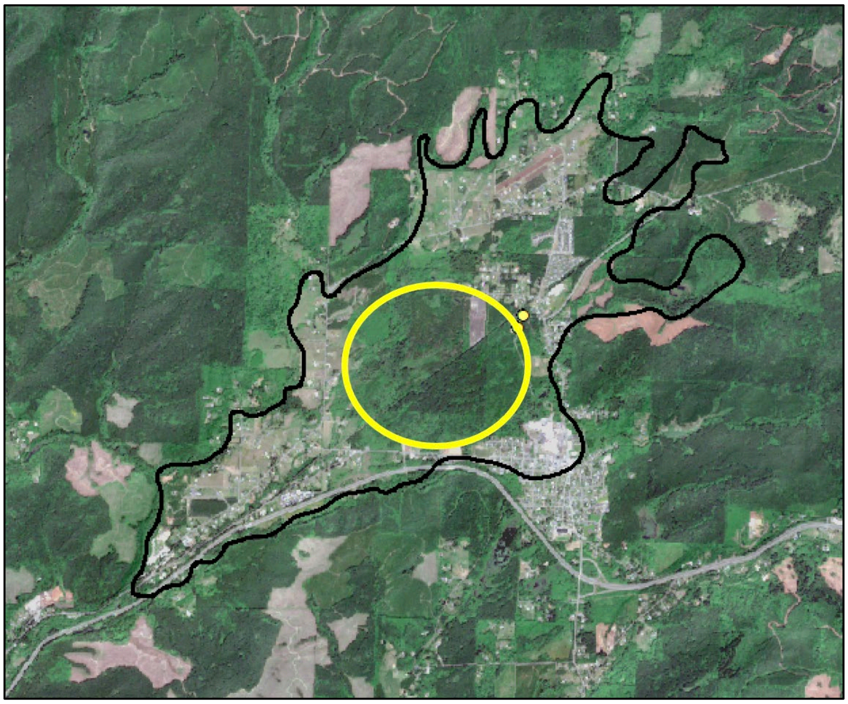

Figure 43. The central portion of the aquifer (yellow circle) where timber harvesting may cause unwanted conditions downgradient.

Recharge to the aquifer likely occurs along the margins of the basin. Although no direct evidence supports changes in groundwater conditions when logging occurs at higher elevations along the boundary, future impacts on groundwater and surface water resources may develop if extensive timber is removed.

5.2.2 Dry Wells

Concerns over reduction in domestic well productively or complete loss of water supply was reported by residents in and around the basin. Although static water levels suggest the aquifer is prolific and maintains stable conditions, reduction in well capacity is possible, assuming no mechanical well performance issues.

Many issues can cause wells to decrease in capacity. Water level in a well is determined by pumping rates, storativity, and transmissivity of the aquifer. Storativity of an aquifer is the addition or release of water to the storage space due to the increase or decrease of hydraulic head. Transmissivity is the thickness of the aquifer multiplied by the hydraulic conductivity, most simply defined as the ease in which groundwater moves thorough the aquifer.

As a well withdrawal groundwater, a cone of depression forms. The shape of the cone and the water level in the well is dictated by the pumping rate and inversely proportional to aquifer transmissivity and aquifer storativity (Figure 44).

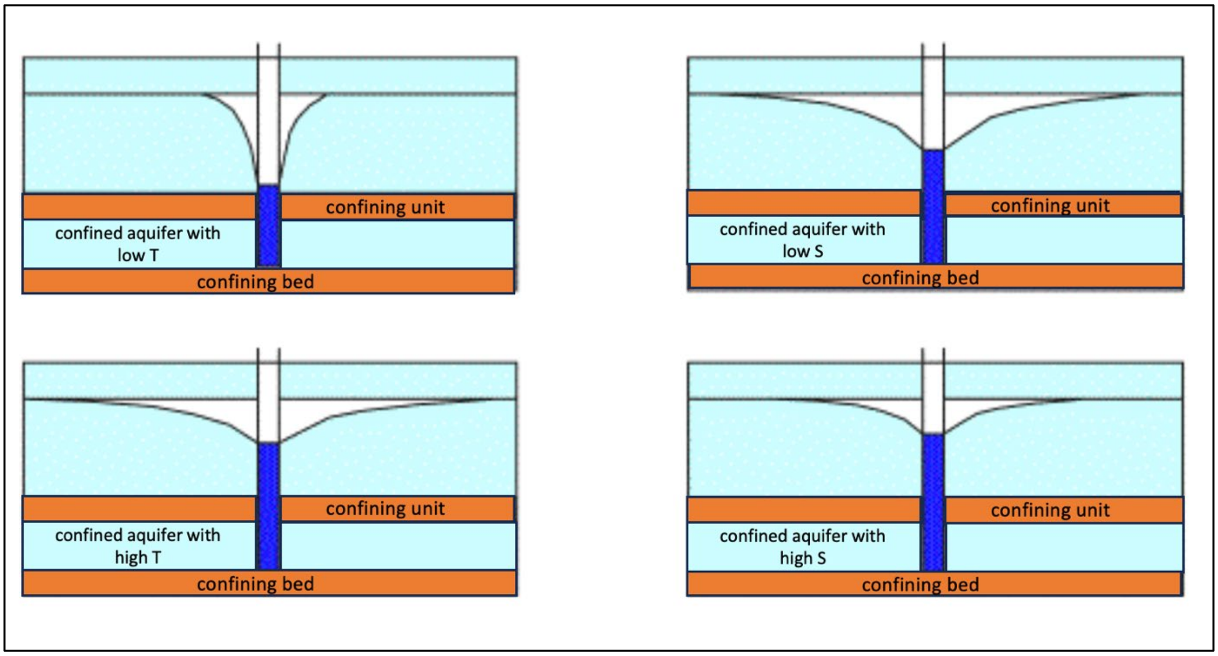

Figure 44. Changes in water level at a well, based on storativity (S) and transmissivity (T) of a confined aquifer with a constant pumping rate (modified from (Freeze & Cherry, 1979). In this example, the shape and width of the cone of depression, and water level, varies according to these parameters.

A cone of depression is formed as water is removed from storage. When two wells are in close proximity, well interference may occur, causing two cones of depressions to overlap. This reduces water availability for both wells (Figure 45).

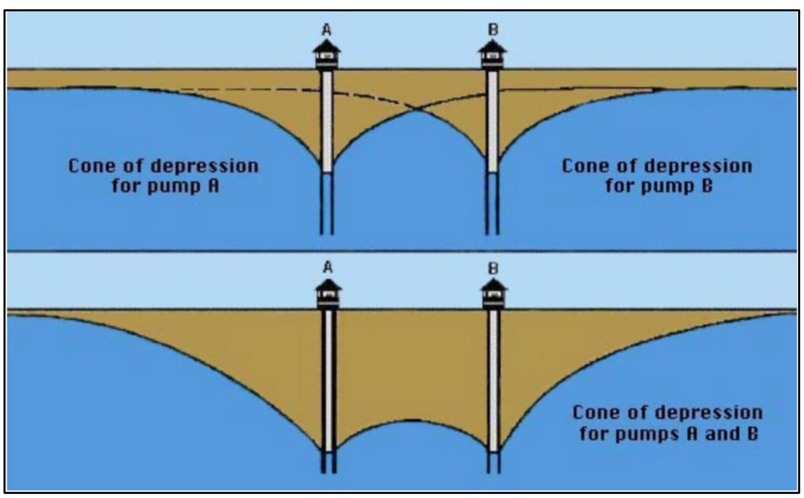

Figure 45. PLACEHOLDER (will update with new image) Well interference and the reduction of water level in each well due to the overlapping cone of depression for pump A and pump B.

Well interference can be avoided by properly designing and spacing out wells where the water level remains undisturbed. Figure 46 shows an example of well interference between two closely spaced wells verses a well which is properly distanced and maintains higher levels of water.

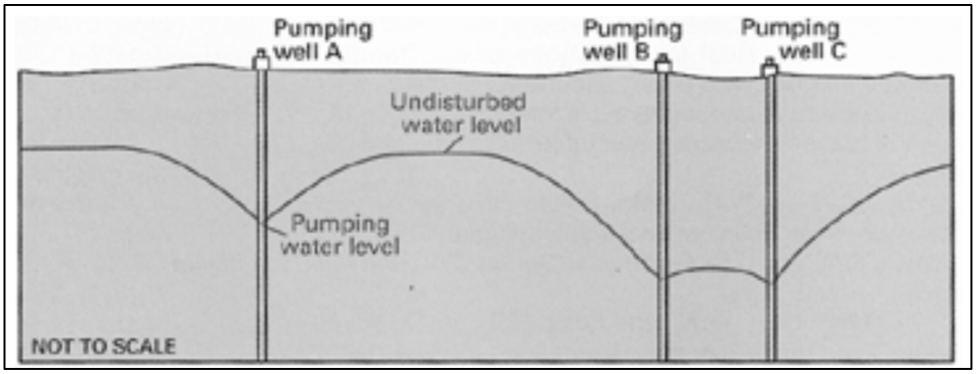

Figure 46. (PLACEHOLDER will update with new image) Well interference between two wells (C and B) create a lower water level within both wells verses a well (A) with a higher water level that is located outside the influence of other wells.

Although every attempt was made to locate well logs for wells reported to have gone dry for a period of time, none were available. In general, the locations of these wells suggest most access the shale, which is less transmissive than Aquifer 1 and Aquifer 2. Recent developments along the southwestern portion of the aquifer show most new wells were drilled in the shale. Given the close proximity to each well, it is possible water levels in the area declined due to interference.

5.3 Project Management Actions

The following describes the projects proposed to fill data gaps, evaluate management options, and encourage public outreach.

5.3.1 Project 1: Monitoring, Testing, and Modeling

Additional monitoring and testing are required to improve our understanding of aquifer conditions and to model safe yield scenarios. The following discusses the monitoring projects and are shown in Figure 47.

Northeast Upland Boundary: conduct test borings and observation well installation on the northeast portion of the aquifer where groundwater flow data is sparse. This will allow for monitoring of seasonal groundwater fluctuations and enhanced understanding of recharge to the aquifer.

Wildcat Creek: install a staff gauge below the confluence of the Wildcat Creek to systematically measure flows throughout the year, especially during the dry season. Gages in one or more of the forks could also be useful.

City Wells: record water level and pumping data at the City's water supply wells.

Vertical Hydraulic Gradient - Near City Wells: characterization of the vertical hydraulic gradient between the upper and lower aquifer can be accomplished (as recommended in Horsley Witten Group, 2008) by installing monitoring wells along a 20-, 100, and 400-foot transect from the pumping wells. Two wells accessing the shallow and deeper aquifers should be installed at each site.

Vertical Hydraulic Gradient - Southwest Area: observation wells should be installed where till is not present in the upper and lower area of the aquifer, with at least two multi-level wells at each site to to determine vertical gradients, especially where standing groundwater in the lower portion of the basin has been reported.

Modeling: basin-wide modeling will assess the extent water can be pumped from the aquifer without causing unacceptable harm, in addition to evaluating different management scenarios.

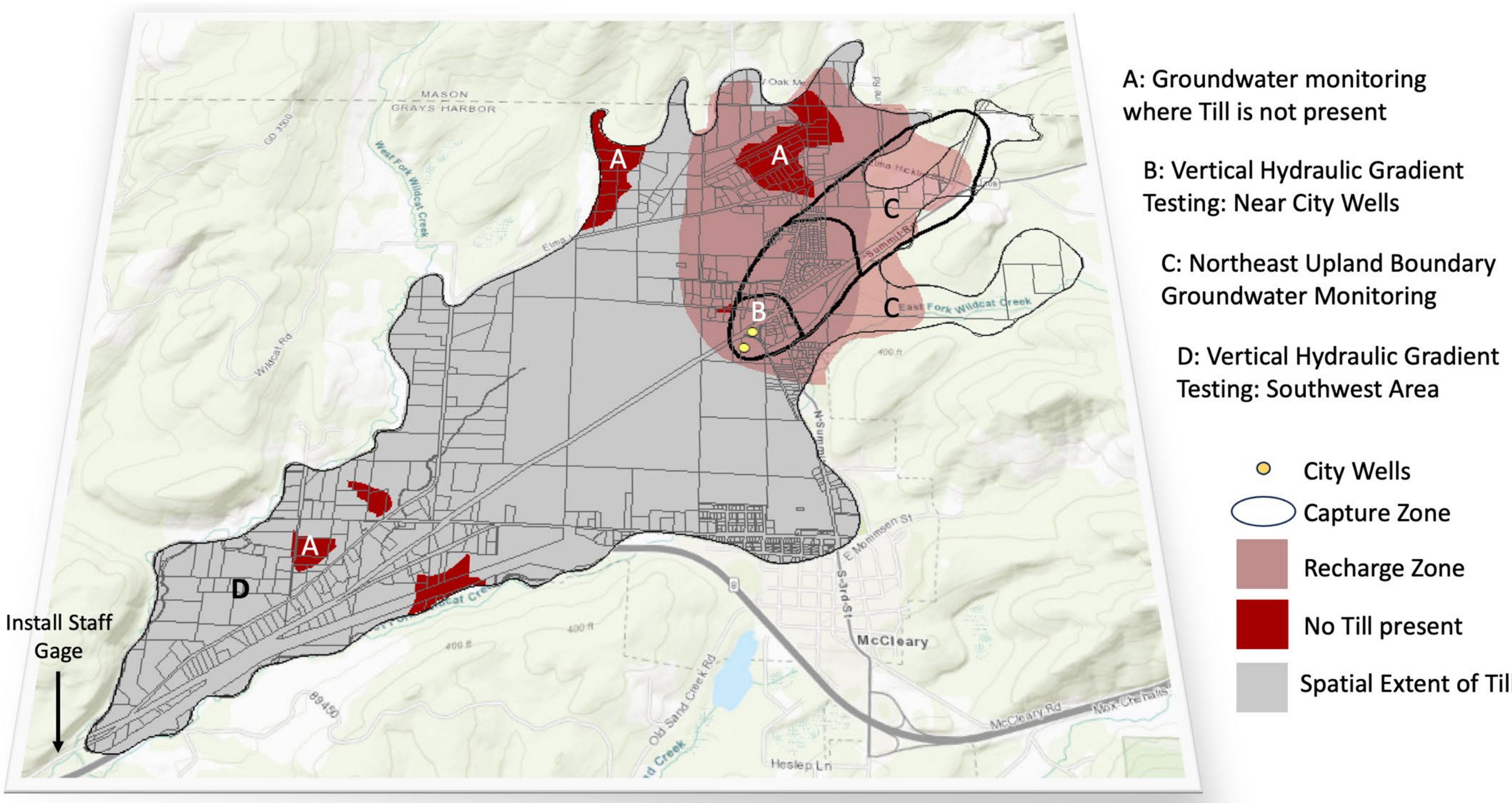

Figure 47. Project 1: Monitoring recommendations in the Wildcat Creek and Wildcat Creek Aquifer

5.3.2 Project 2: Water Quality Testing and Land Use Evaluation

Water Quality Testing

Septic system failure poses a threat to water quality. To identify the extent in which nitrates may contaminate drinking water requires a private water quality testing program, especially in locations where till is not present and septic system density is high. Testing should take place every few years. Additional testing for pesticides and household contaminants would provide background concentrations that could be used to test for changes in future conditions.

Land Use

Additional evaluation of water quality concerns on current and future land use changes upgradient of the city wells should be conducted to reduce contaminants entering the aquifer where till is not present.

5.3.3 Project 3: Evaluate Ordinances

Sole Source Aquifer Protection Program: The City of McCleary could petition EPA to evaluate the Wildcat Creek Aquifer for sole source aquifer designation. Doing so could also afford additional protection of the aquifer at the state level.

5.3.4 Project 4: Improve Reliability of Water Supplies for Basin Users

Utility expansion: the city could evaluate the feasibility of extending services to new private groundwater users in the basin to limit the installation of new septic systems and prevent leaching of nitrates.

5.3.5 Project 5: Managed Aquifer Recharge

The City should apply for a Streamflow Restoration Grant from the Department of Ecology to identify suitable locations and implement a **Managed Aquifer Recharge** (MAR) Program for the purpose of protecting streamflow in Wildcat Creek. The MAR program would be designed to capture and store water when available (during high precipitation months) for enhanced aquifer recharge for the purpose of providing additional baseflow to Wildcat Creek that could mitigate for consumptive uses of groundwater withdrawals in the basin.

5.3.6 Project 6: Public Outreach

The City should provide public education material on the aquifer, potential contaminants, and a water well owner's handbook that discusses well efficiency, construction, and maintenance on its website, and provide an avenue for residents to submit possible overdraft issues.

5.4 Project Implementation

To achieve sustainable use of the Wildcat Creek Aquifer requires implementing a plan that allows for varying groundwater management scenarios, which are foundationally structured on accurate hydrogeologic characteristics. The addition of these projects throughout the basin will provide an avenue to allow for different modeling scenarios and respective management decisions that support sustainability of the Wildcat Creek Aquifer (Figure 48).

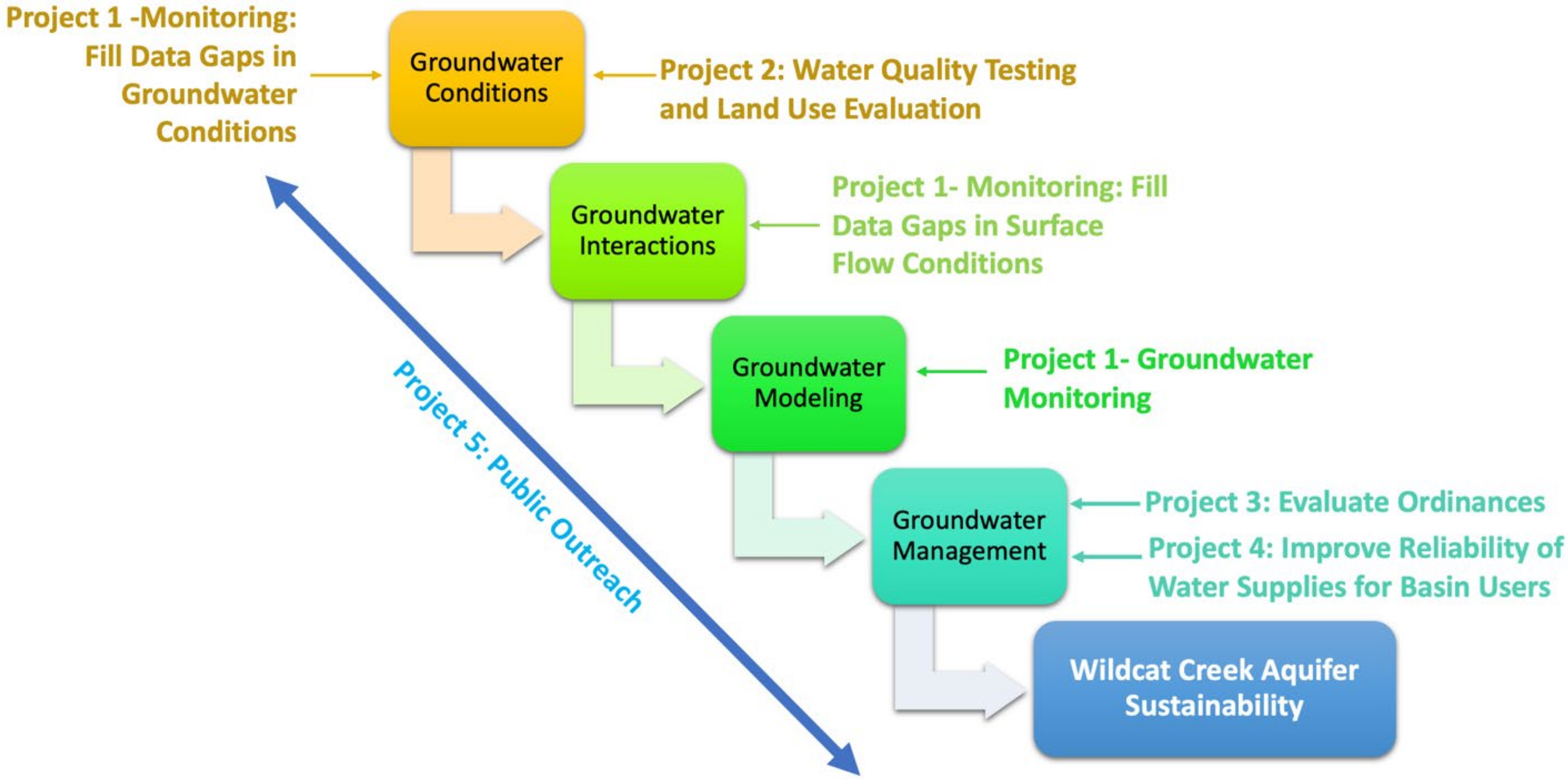

Figure 48. Process and proposed projects to achieve sustainability in the Wildcat Creek Aquifer.

6 Plan Implementation

6.1.1 Implementable Schedule

6.1.2 Implementable Cost and Funding Sources

6.2 Five-Year Evaluation Reporting

7 Conclusion

8 References

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Appendix A: Survey Results

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 13, 2022 7:27 AM

Location

Water Supply

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Water supply with the increased development. If the study shows that the aquifer can sustain the growth then ok but prove it. My neighbors well has run dry and its the first time in 22 years. That's a reason for concern!

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 25, 2022 8:24 PM

Location

2

Water Supply

Well Water

If you are on well water, is your supply stable?

Yes

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Water Quality, 3. Habitat Health, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

Too many!

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 25, 2022 9:39 PM

Location

Water Supply

Well Water

If you are on well water, is your supply stable?

No. It has ran dry since the new homes projects where placed in McCleary

Future concerns over water?

9

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Water supply and the mass production of houses in our small rural town. We don't want more housing complexes. We don't need them. And we can't support them.

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 25, 2022 9:40 PM

Location

0 in city limits

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

9

Greatest concern over the future of water?

1. Water Quality, 2. Water Supply, 3. Population and Land Development, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 25, 2022 11:40 PM

Location

2

Water Supply

Well Water

If you are on well water, is your supply stable?

Unknown

Future concerns over water?

6

Greatest concern over the future of water?

1. Water Supply, 2. Water Quality, 3. Habitat Health, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 26, 2022 1:44 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Population and Land Development, 2. Water Supply, 3. Water Quality, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 26, 2022 4:27 PM

Location

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

5

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 26, 2022 7:32 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

City well seems to provide.

Future concerns over water?

10

Greatest concern over the future of water?

1. Population and Land Development, 2. Water Quality, 3. Water Supply, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

County management

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 26, 2022 10:49 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 27, 2022 9:44 AM

Location

Live within city limits

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 30, 2022 12:05 PM

Location

Water Supply

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 30, 2022 4:39 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

9

Greatest concern over the future of water?

1. Habitat Health, 2. Water Supply, 3. Water Quality, 4. Other, 5. Population and Land Development

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: October 30, 2022 9:06 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

We already have water issues: smells & mineral build up. I hope McCleary can take control of the annex so that the city & the community can make proper plans for McCleary. Thank you.

Questionnaire

Submitted By: Anonymous user

Submitted Time: November 1, 2022 8:37 PM

Location

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

6

Greatest concern over the future of water?

1. Population and Land Development, 2. Water Quality, 3. Water Supply, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: December 11, 2022 11:22 AM

Location

2.5 miles

Water Supply

Well Water

If you are on well water, is your supply stable?

Fairly stable

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Population and Land Development, 3. Water Quality, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: February 3, 2023 11:00 AM

Location

Water Supply

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 16, 2023 6:51 PM

Location

We are in City limits.

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Other, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Water Quality

Other concerns over the future of water that you would like to share?

All of the above. Stop poisoning the water. Public Disclosure is necessary especially for people building and purchasing homes in McCleary. Notification to the people when you do the chemical dump. The water is bad and is making people sick.

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 16, 2023 6:54 PM

Location

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Quality, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

We had our water tested by a private lab and the chlorine in the water is far too high. At these levels, plumbers warn your system will fail before life expectancy. Not safe to bath children in.

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 16, 2023 10:22 PM

Location

In Mccleary County

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Habitat Health, 2. Water Supply, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 17, 2023 8:32 AM

Location

0

Water Supply

Well Water

If you are on well water, is your supply stable?

Yes

Future concerns over water?

8

Greatest concern over the future of water?

1. Population and Land Development, 2. Water Supply, 3. Habitat Health, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 17, 2023 11:21 AM

Location

In town 4th st

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Quality, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

Health of kids, family, pets. To be able to use the water without fear and not having to source water from outside sources.

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 17, 2023 12:42 PM

Location

Water Supply

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Quality, 2. Water Supply, 3. Habitat Health, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 17, 2023 2:59 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

9

Greatest concern over the future of water?

1. Water Quality, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

The water some times smells like a swimming pool when I take showers, it gives my hair split ends and it’s to gross for me and my pets to drink

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 17, 2023 3:08 PM

Location

1 mile out

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: March 20, 2023 5:09 PM

Location

In the city

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Quality, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 11, 2023 7:44 PM

Location

3 miles

Water Supply

Well Water

If you are on well water, is your supply stable?

Yes

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Supply, 2. Population and Land Development, 3. Water Quality, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

The City of McCleary does not make its consumer confidence report readily available to city water users. When one inquired, they responded “submit a freedom of information act request for it”. They do not have a history of transparency.

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 12, 2023 9:43 AM

Location

Within City Limits

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

10

Greatest concern over the future of water?

1. Habitat Health, 2. Water Supply, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Addressing the tons of buried asphalt

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 13, 2023 5:36 AM

Location

1

Water Supply

Well Water

If you are on well water, is your supply stable?

Yes

Future concerns over water?

6

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 22, 2023 10:32 AM

Location

2.5 miles

Water Supply

Well Water

If you are on well water, is your supply stable?

yes

Future concerns over water?

10

Greatest concern over the future of water?

1. Population and Land Development, 2. Water Quality, 3. Water Supply, 4. Habitat Health, 5. Other

Other concerns over the future of water that you would like to share?

I'm concerned about pollution caused by pesticides, herbicides and other chemicals.

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 22, 2023 2:06 PM

Location

2

Water Supply

Well Water

If you are on well water, is your supply stable?

So far, yes, over 33 years.

Future concerns over water?

9

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Disregard for water use, chemicals on lawns, pesticides and blatant lack of education before residency and all pollution affects all.

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 23, 2023 6:29 AM

Location

1 mile from downtown.

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

8

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

A city master plan must center aquifer on carrying capacity, and given rural development and wells permitted outside City limits, partnering with the county will be important. Additionally, the city needs to protect key recharge areas from development.

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 23, 2023 12:50 PM

Location

0

Water Supply

City

If you are on well water, is your supply stable?

Future concerns over water?

7

Greatest concern over the future of water?

1. Water Supply, 2. Habitat Health, 3. Population and Land Development, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 24, 2023 11:06 AM

Location

Seven

Water Supply

Well Water

If you are on well water, is your supply stable?

Yes

Future concerns over water?

7

Greatest concern over the future of water?

1. Population and Land Development, 2. Habitat Health, 3. Water Supply, 4. Water Quality, 5. Other

Other concerns over the future of water that you would like to share?

Draining of wetlands and streams for development.

Questionnaire

Submitted By: Anonymous user

Submitted Time: April 24, 2023 6:25 PM

Location

2.5

Water Supply

Well Water

If you are on well water, is your supply stable?

Think so

Future concerns over water?

10

Greatest concern over the future of water?

1. Water Quality, 2. Habitat Health, 3. Water Supply, 4. Population and Land Development, 5. Other

Other concerns over the future of water that you would like to share?