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Feasibility Study to Mitigate Groundwater Impacts through Storage in Skagit Basin

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Feasibility Study to Mitigate Groundwater Impacts through Storage in Skagit Basin

by
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Rebecca Inman

Summarizing a report by
State of Washington Water Research Center
Skagit Basin Water Mitigation Feasibility Assessment
by
Michael Brady et al.

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Executive Summary

The Department of Ecology (Ecology) adopted the Instream Resources Protection Program rule for the Lower and Upper Skagit River Basins on April 14, 2001. Ecology amended the rule in 2006 to provide reservations for rural water use. The Washington State Supreme Court invalidated the 2006 amendment in 2013. Between 2001 and 2013, 451 homes and businesses were developed in the rule area that relied on water from permit-exempt wells, and the reservations established in the 2006 rule amendment. In effect, the invalidation of the 2006 rule amendment left those homes and businesses without a legal water supply.

Since 2013, Ecology has been working on potential water solutions for those homes and businesses. In 2016, the Legislature passed Engrossed Senate Bill 6589 requiring Ecology to conduct a feasibility study on "effectively sized storage" to recharge the Skagit River basin when flows are not met.

Ecology contracted with Washington State University (WSU) School of Economic Sciences to conduct the feasibility study. WSU's analysis focused on three mitigation options not previously analyzed:

- Piped water using public water system inchoate water rights
- Trucked water
- Winter flow capture (high streamflow capture)

Each required the installation of an appropriately sized cistern (or pond) at augmentation points, from which water would be released to recharge the river system when needed. By collecting water, storing and later releasing it to either shallow aquifers in direct connection with streams, or into streams directly, the options would mitigate the water used by homeowners from their individual wells. The three methods vary most in the source of the recharge water.

WSU's analysis concluded that:

- Trucking water for mitigation is the least expensive option for most sub-basins when considering *in-house use only*.
- Piping water for mitigation is the least expensive option in every sub-basin when considering *indoor/outdoor water use*.
- Piping water for mitigation is less expensive per household where there are many homes within the sub-basin to share the expense of the pipe installation.
- Winter flow capture may be the least expensive mitigation option for the more remote parcels.

The trucking and piping mitigation approaches would need further evaluation to determine how best to ensure long-term operations and maintenance. The impacts on air quality, noise, and roads from widespread use of trucking would be difficult to address.

The use of inchoate[1] municipal water rights for mitigation purposes may require a formal water right change to change the purpose and place of use. Clear legislative authorization to allow use of municipal inchoate water rights for mitigation purposes in the Skagit Basin would help avoid litigation.

Ecology recommendations

To implement any of the three options, the next step would be to conduct a pre-engineering level assessment to refine the costs and address other feasibility questions. To ensure compliance with the Growth Management Act (GMA), any mitigation strategy would need to be limited to supporting rural level of services.

Ecology recommends further assessment on the viability of piped water mitigation in the Skagit/Delta-Frontal sub-basin, which includes the Carpenter and Fisher Creek drainages. This recommendation is based on:

- This sub-basin is in the lowest cost category, so it is the most cost effective of any of the sub-basins analyzed by WSU.
- The total cost of mitigating existing water users in this basin is estimated at about $1.1 million.
- The density of the existing homes without a legal water supply is high.
- The basin has the highest likelihood of future development significantly impacting stream flows.
- Piped water becomes more cost effective over time as more development occurs and more property owners share in the capital cost outlays to construct the basic infrastructure.
- A successful piped water mitigation project in these sub-basins could be extended to the adjacent Nookachamps Creek headwaters, another area of significant demand.

[1] Inchoate water rights are the portion of a water right that has not yet been put to beneficial use.

Introduction

This report has been prepared to fulfill the requirements of chapter 227, laws of 2016 (Engrossed Senate Bill 6589). That bill requires Ecology to conduct a study to examine the feasibility of using "*effectively sized water storage to recharge the Skagit river basin when needed to meet minimum instream flows and provide non-interruptible water resources to users of permit exempt wells within the Skagit river basin.*" The bill states:

> *(1) The department of ecology, in cooperation with the state department of health, Skagit county, tribes, and nonmunicipally owned public water systems in Skagit county, shall conduct a study to examine the feasibility of using effectively sized water storage to recharge the Skagit river basin when needed to meet minimum instream flows and provide noninterruptible water resources to users of permit exempt wells within the Skagit river basin.*
>
> *(2) The department of ecology must submit a report of the study's findings to the standing committees of the legislature with oversight of water resources and fiscal issues by December 1, 2016.*
>
> *(3) This section expires on December 1, 2016.*

The Department of Ecology (Ecology) contracted with Washington State University's (WSU) Water Research Center to conduct the analysis for the storage feasibility study, and convened an advisory group consisting of members from the following entities:

- State Department of Health
- Affected counties
- Tribes with established reservation land in the Skagit Watershed
- Public water systems
- Legislators and legislative staff

The advisory group met twice (June and August 2016) to provide feedback to WSU in the development of their report.

This report:
- Provides an overview of the WSU report's findings.
- Includes a discussion of other considerations, including operational and legal concerns.
- Identifies next steps.

WSU's complete analysis is provided in Appendix A.

Background

Ecology adopted the Instream Resources Protection Program rule for the Lower and Upper Skagit River Basins (Skagit Rule) on April 14, 2001. The Skagit Rule, WAC 173-503, established instream flows necessary to protect and preserve wildlife, fish, scenic, aesthetic, and other environmental values; and provided for the protection of navigation, recreation, and water quality.

In 2003, Skagit County challenged the 2001 rule, claiming that the Skagit Rule failed to adequately provide for growth in rural areas not served by public water systems. Property owners continued to construct homes and businesses reliant on permit-exempt wells after the 2001 rule adoption, relying on regulations in place at the time.

In 2006, Ecology amended the Skagit Rule in response to the lawsuit brought by Skagit County. The 2006 amendment established reservations for future year-round water use and closed several tributary streams to further appropriation. The 2006 amendment included provision for those homes and businesses developed between 2001 and 2006 in the allocation of the reserves.

In 2008, the Swinomish Tribal Community challenged the 2006 rule amendment on grounds that the reservations would impair, or had the potential to impair, the Tribe's fishing opportunities and recreational, commercial, spiritual aesthetic, scientific, environmental, and cultural benefits derived by the Tribe and its members.

The rule challenge was brought before Thurston Superior Court, where the court denied the Tribe's petition. The Swinomish Tribe appealed the denial to the Court of Appeals, which certified it to the Washington State Supreme Court. The Supreme Court issued its decision in *Swinomish vs. Ecology* on October 3, 2013, where the Court invalidated the entire 2006 rule amendment.

Between 2001 and 2013, 451 homes and businesses were developed in the rule area (Figure 1, Table 1) that relied on the reservations established in the 2006 rule amendment. Since the Supreme Court ruling invalidated the 2006 rule amendment, those homes and businesses that relied on reservations no longer have a secure, uninterruptible water right, and there is legal uncertainty with their water supply. This has affected property owners' ability to sell, obtain financing, or further develop their property, if they do not hold a water right that predates the Skagit rule.

With the agreement of the Swinomish Tribe, Ecology has exercised enforcement discretion and has not curtailed the water use of those who relied on the 2006 reservations for their water supply while mitigation solutions are sought.

Acquiring senior water rights and using those rights to mitigate new uses is the typical approach used for mitigation. However, in the Skagit Basin, Ecology has had limited success in finding senior water rights to mitigate use of existing wells. This study assesses the feasibility of other possible approaches which would mitigate property owners' use of water by supplementing groundwater recharge or enhancing streamflow directly.

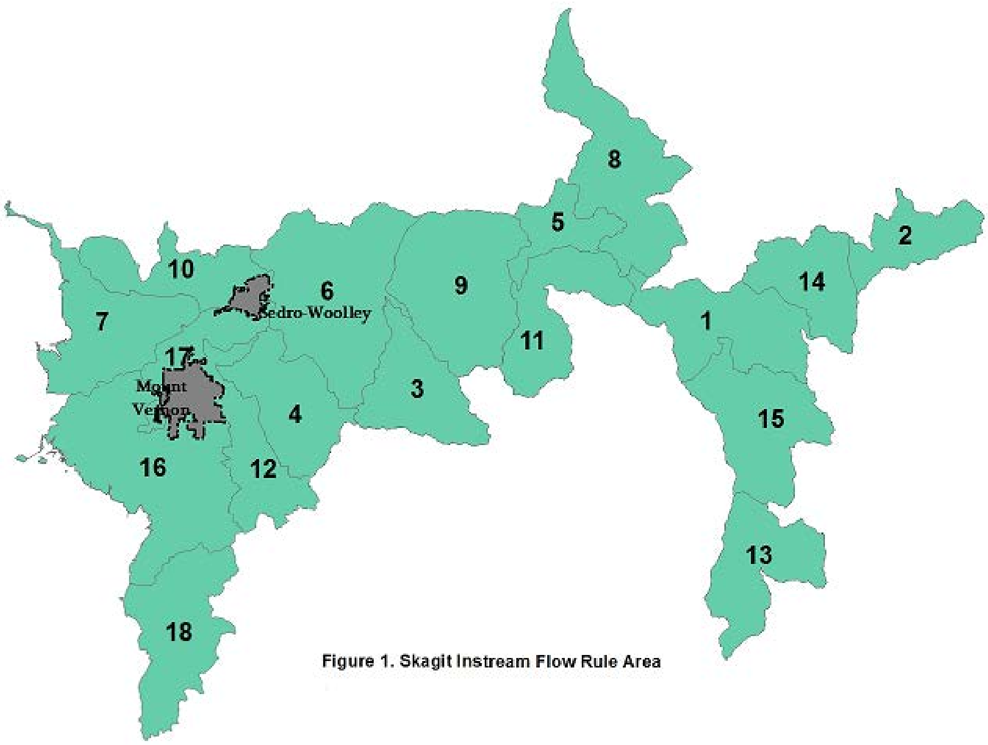

Figure 1. Skagit Instream Flow Rule Area

Table 1. Sub-basin names and map reference numbers.

Map Reference #	Sub-basin Name
1	Aldon Creek-Skagit River
2	Copper Creek-Skagit River
3	Day Creek
4	East Fork Nookachamps Creek
5	Grandy Creek
6	Hansen Creek
7	Joe Leary Slough-Frontal Padilla Bay
8	Lake Shannon-Baker River
9	Loretta Creek-Skagit River
10	Lower Samish River
11	Mill Creek-Skagit River
12	Nookachamps Creek
13	Prairie Creek-Sauk River
14	Rocky Creek-Skagit River
15	Sauk River
16	Skagit Delta-Frontal Skagit Bay
17	Skagit River
18	Stillaguamish River-Frontal Port Susan

Mitigation for parcels developed between 2001 and 2013

Since the 2013 Supreme Court decision, Ecology has been exploring several mitigation options including water banking by acquiring senior water rights. Ecology has been working under legislative provisos to find a legal water supply for the homes and businesses built between 2001 and 2013, and to provide mitigation water for future rural water users in the Skagit Basin (potentially 5,700 rural parcels). That work is ongoing, and will provide additional mitigation options in the future for at least some of the landowners in the Skagit basin.

Study description

The WSU study examines three mitigation scenarios that would allow homeowners who formerly relied on reservations of water to continue to use their wells.. Three mitigation options met these criteria and are described in the following sections:

- Piped water
- Trucked water
- Winter flow capture

To the extent possible, WSU incorporated previous studies into their analysis to avoid duplication of work. WSU's analysis focuses on properties already developed, however cost estimates reported in this study can be used to consider mitigation costs for new construction.

Assumptions used

- Indoor consumptive water use: 15 gallons per day for residences on a septic system. This is based on 150 gallons total use with 90 percent returned via septic recharge.
- Outdoor water use (all consumptive): 71.42 gallons per day.
- Mitigation costs are based on a 30-year time horizon.
- Analysis was done at the Hydrologic Unit Code[2], or HUC-12 (sub-watershed) scale.
- Mitigation was assumed to be provided within the same HUC-12.
- Mitigation would be made by augmenting the mainstem of each HUC-12 sub-basin, rather than the closest surface water body (e.g., tributary).
- Mitigation would occur at one point on the mainstem for all parcels in that HUC-12 sub-basin.

Limitations of the study

The WSU study is not a comprehensive analysis of the many mitigation alternatives that may be available in the Skagit basin. Rather, it focuses on a subset of mitigation alternatives related to

2 **hydrologic unit code** is a sequence of numbers or letters that identify a hydrological feature like a river, river reach, lake, or area like a drainage basin, watershed, or catchment.

appropriately-sized storage for the affected home and business owners, to meet the intended goal of the study directed by the Legislature.

Planning level cost assumptions are based on modeled results. Actual costs can only be developed doing more detailed, site-specific analysis.

Legal considerations

Two of the three mitigation options considered in this study (piping and trucking) rely on the use of inchoate municipal water rights to provide water for mitigation. There may be legal constraints related to the municipal water purveyor's service area and purposes of use described in their water rights that would need to be resolved before this water could be used for mitigation.

To ensure compliance with the Growth Management Act (GMA), any mitigation strategy would need to be limited to supporting rural level of services.

Using Piped Water to Mitigate for Stream Flow Impairment

WSU studied the cost of construction and maintenance of extending public water system infrastructure to provide a volume of water that would meet mitigation needs for parcels developed between 2001 and 2013. Water would be pumped from existing municipal systems to a cistern at a single upstream point in each HUC-12 (sub-basin) using small gauge pipes. Water would then be released slowly as recharge to the aquifer or direct stream flow augmentation in the summer months to offset well-pumping impacts, thus enabling property owners to continue using their wells.

WSU evaluated the costs of mitigating indoor water use, and indoor/outdoor use. Figure 2 and Table 2 detail the estimated costs of piping water to mitigate indoor use only. Figure 3 and Table 3 show the costs of mitigating indoor/outdoor water use. The estimates are based on the most up-river cost, which places the point of recharge on the tributary at the point closest to the most upstream affected parcel in the sub-basin. For ease of identifying locations on the map, we have provided reference numbers for each sub-basin in the following tables.

The amount of water required to mitigate for cumulative water use from parcels developed between 2001 and 2013 is relatively small due to septic return flow. Because of this, WSU estimated costs based on the smallest size of pipe feasible to install and maintain (1-inch or smaller). This small diameter pipe modeled by WSU would supply sufficient flow for the mitigation needed in all basins with some additional capacity.

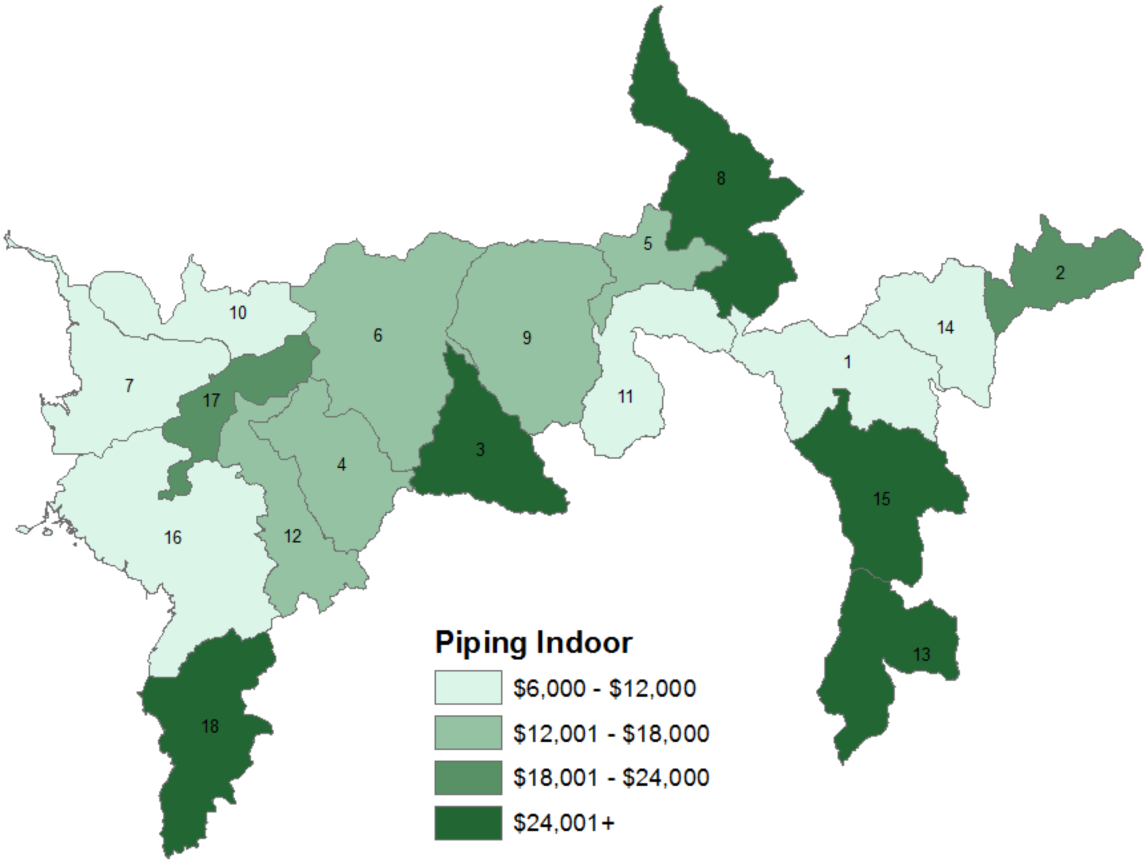

Figure 2. Cost by sub-basin using piped water for mitigation—indoor use only.

Costs

Costs listed in tables 2 and 3 below are present value (PV) amounts, combining the initial construction (one-time) and reoccurring operation and maintenance costs (over a 30 year period) into a single comparable value.

Indoor use only

Table 2. Cost by sub-basin using piped water for mitigation—indoor use only.

Map Reference #	Sub-basin	Number of Homes/ Businesses	Estimated Cost per Household/ Business	Sub-basin Total
1	Aldon Creek-Skagit River	39	$11,635	$453,765
2	Copper Creek-Skagit River	9	$21,055	$189,495
3	Day Creek	3	$118,493	$355,479
4	East Fork Nookachamps Creek	17	$14,463	$245,871
5	Grandy Creek	28	$15,291	$428,148
6	Hansen Creek	79	$13,579	$1,072,741
7	Joe Leary Slough-Frontal Padilla Bay	17	$10,996	$186,932
8	Lake Shannon-Baker River	1	$88,803	$88,803
9	Loretta Creek-Skagit River	28	$17,833	$499,324
10	Lower Samish River	7	$10,702	$74,914
11	Mill Creek-Skagit River	52	$7,600	$395,200
12	Nookachamps Creek	33	$12,211	$402,963
13	Prairie Creek-Sauk River	23	$53,881	$1,239,263
14	Rocky Creek-Skagit River	7	$9,365	$65,555
15	Sauk River	6	$51,948	$311,688
16	Skagit Delta-Frontal Skagit Bay	94	$8,367	$786,498
17	Skagit River	1	$23,959	$23,959
18	Stillaguamish River-Frontal Port Susan	7	$48,045	$336,315
			Total	$7,156,913

Indoor/outdoor water use

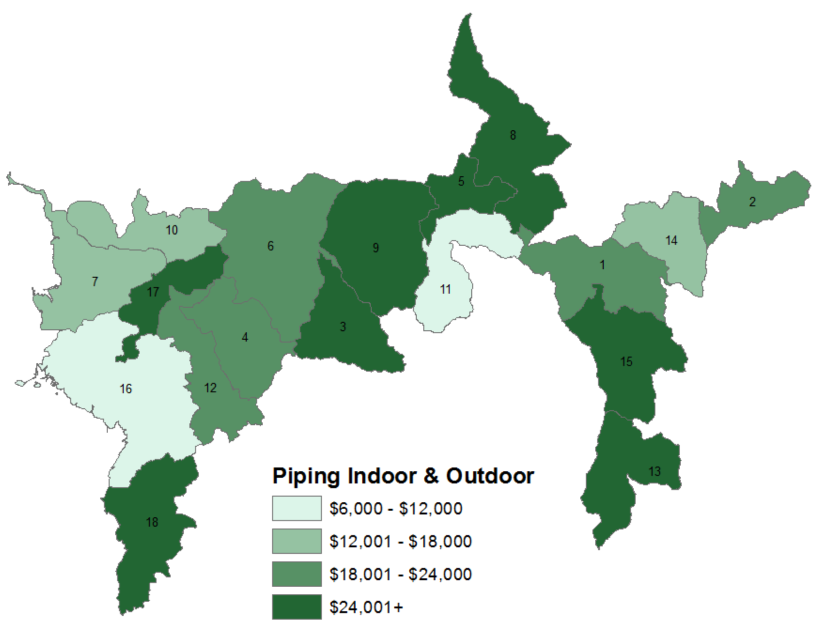

Figure 3. Cost by sub-basin using piped water for mitigation—indoor/outdoor water use.

Table 3. Cost by sub-basin using piped water for mitigation—indoor/outdoor water use

Map Reference #	Sub-basin Name	Number of Homes/ Businesses	Estimated Cost per Household/ Business	Sub-basin Total
1	Aldon Creek-Skagit River	39	$18,582	$724,698
2	Copper Creek-Skagit River	9	$23,949	$215,541
3	Day Creek	3	$121,383	$364,149
4	East Fork Nookachamps Creek	17	$23,873	$405,841
5	Grandy Creek	28	$25,803	$722,484
6	Hansen Creek	79	$19,548	$1,544,292
7	Joe Leary Slough-Frontal Padilla Bay	17	$16,904	$287,368
8	Lake Shannon-Baker River	1	$91,693	$91,693
9	Loretta Creek-Skagit River	28	$30,856	$863,968
10	Lower Samish River	7	$13,593	$95,151
11	Mill Creek-Skagit River	52	$10,687	$555,724
12	Nookachamps Creek	33	$19,677	$649,341
13	Prairie Creek-Sauk River	23	$102,913	$2,366,999
14	Rocky Creek-Skagit River	7	$12,254	$85,778
15	Sauk River	6	$54,844	$329,064
16	Skagit Delta-Frontal Skagit Bay	94	$11,742	$1,103,748
17	Skagit River	1	$26,849	$26,849
18	Stillaguamish River-Frontal Port Susan	7	$50,965	$356,755
			Total	$10,789,443

WSU’s estimates in Table 3 above reflect a significantly lower cost for piping water to provide mitigation than extending piped water service directly to each parcel for two reasons:

- Larger pipelines constructed of more expensive materials (to maintain higher pressure) are required to provide direct water service.
- Groundwater recharge or streamflow augmentation would occur only to a single point in each sub-basin (although there may be areas where additional augmentation points make sense based on fish habitat needs, which would increase costs).

If additional properties are developed and mitigated with piped water, the cost per property would drop even further because the cost would be spread among more users.

Some sub-basins are relatively lower cost than the other methods assessed by WSU; for example, the Skagit Delta-Frontal Skagit Bay mitigation is estimated to cost $11,742 per parcel for indoor/outdoor use. Costs to pipe water for mitigation are considerably higher in other sub-basins, such as the Day Creek sub-basin, at $118,493 per parcel for indoor use only, far exceeding the cost of other mitigation strategies that could be used. The costs vary by the distance the water must be piped and the number of households that would share the expense.

Increased property value appears to offset the additional mitigation costs of outdoor water use. For most properties, piping water for mitigation is the most cost-effective option of the three alternatives explored when outdoor water use is included.

Additional considerations

Treatment

Drinking water is treated with chlorine to ensure it does not have microbiological contaminants. Chlorine cannot be discharged directly into the environment, either to surface or groundwater because of environmental impacts. Because piping water for mitigation would involve using treated drinking water to provide mitigation, treatment to remove the chlorine would be required to meet water quality discharge requirements. These costs have not been included in the cost estimates and they could be significant.

Operations and maintenance

Installation of piping, storage, discharge, and treatment facilities would need to be managed in perpetuity. Potentially, Skagit PUD or another public entity could take responsibility for operations and management. However, a new entity may need to be created for long term operations and maintenance, such as a utility district or local improvement district. If an existing purveyor were to take on responsibility for operating the system for mitigation, they would have to adjust water system planning documents, evaluate rates and staffing, and review existing water rights.

Limitations on analysis

Additional detailed analysis with actual costs versus planning level (modeled) costs would be needed to get at precise costs, including the cost of easements. Actual cost would also depend on augmentation points within each sub-basin.

Using Trucked Water to Mitigate for Stream Flow Impairment

WSU studied the costs of using trucked water to provide a volume of water that would meet the mitigation needs for parcels developed between 2001 and 2013. Water would be delivered to a cistern at a single upstream point in each sub-basin. Water would then be released slowly as recharge to the aquifer or direct stream flow augmentation in the summer months to offset well-pumping impacts, thus enabling property owners to continue using their wells. Trucks would deliver water to refill cisterns as frequently as needed.

WSU evaluated the costs of mitigating indoor use only, and indoor/outdoor use. WSU developed costs for each parcel based on its location within the sub-basin for indoor use (Figure 4, Table 4), and indoor/outdoor water use. The estimates are based on the most up-river cost, which places the point of recharge on the tributary at the point closest to the most upstream affected parcel in the sub-basin.

Costs

Trucked water is financially feasible to mitigate for in-house use only. If outdoor water use is considered, trucking water becomes cost-prohibitive.

Trucking costs do not become cheaper with future development on a per parcel basis. The increased demand would cause a proportional increase in the frequency of water deliveries, and the cost of each delivery remains unchanged. However, trucking water for streamflow mitigation may be the most feasible option in basins with a low density of parcels needing mitigation.

WSU's estimates reflect a significantly lower cost to using trucked water for mitigation, versus trucking water to provide drinking water supply to each parcel, as much less water is needed for mitigation purposes than to meet household needs. Additionally, cost savings are incurred because groundwater recharge or streamflow augmentation would occur only to a single point in each sub-basin[3] so would only require a single cistern and the related appurtenances.

Indoor use only

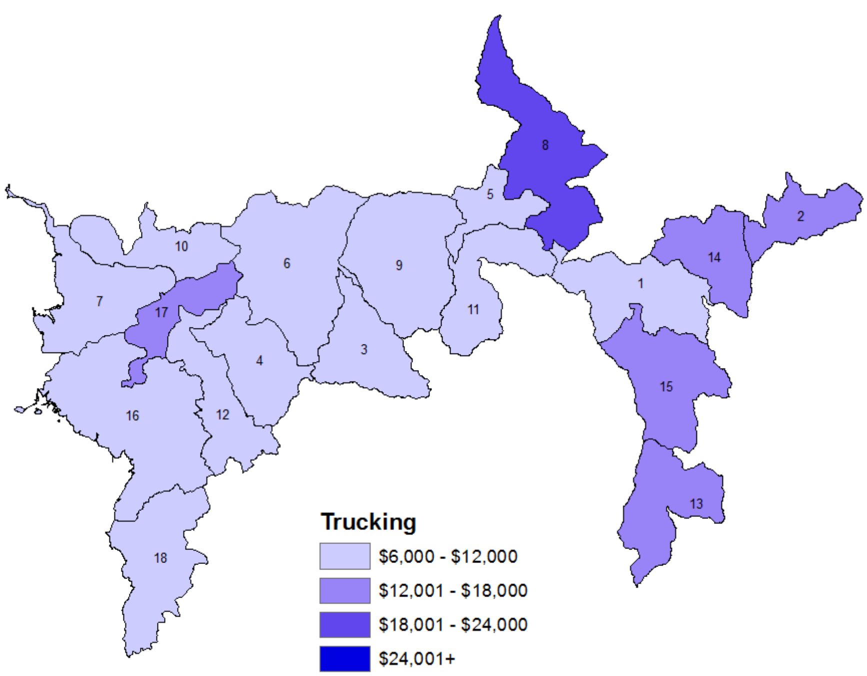

Figure 4. Cost by sub-basin using trucked water for mitigation—indoor use only.

[3] If additional augmentation points in a sub-basin are needed to address fish habitat impacts, additional cisterns and the related appurtenances may be necessary. This would be true for any of the three options in the study.

Table 4. Cost by sub-basin using trucked water for mitigation—indoor use only.

Map Reference #	Sub-basin	Number of Homes/ Businesses	Estimated Cost per Household/ Business	Sub-basin total
1	Aldon Creek-Skagit River	39	$11,177	$435,903
2	Copper Creek-Skagit River	9	$12,793	$115,137
3	Day Creek	3	$11,736	$35,208
4	East Fork Nookachamps Creek	17	$6,639	$112,863
5	Grandy Creek	28	$8,648	$242,144
6	Hansen Creek	79	$7,909	$624,811
7	Joe Leary Slough-Frontal Padilla Bay	17	$6,582	$111,894
8	Lake Shannon-Baker River	1	$21,002	$21,002
9	Loretta Creek-Skagit River	28	$8,465	$237,020
10	Lower Samish River	7	$8,045	$56,315
11	Mill Creek-Skagit River	52	$11,186	$581,672
12	Nookachamps Creek	33	$6,469	$213,477
13	Prairie Creek-Sauk River	23	$14,556	$334,788
14	Rocky Creek-Skagit River	7	$13,882	$97,174
15	Sauk River	6	$13,584	$81,504
16	Skagit Delta-Frontal Skagit Bay	94	$6,190	$581,860
17	Skagit River	1	$16,152	$16,152
18	Stillaguamish River-Frontal Port Susan	7	$7,970	$55,790

Indoor/outdoor water use

Once outdoor use is added, the cost for trucking water becomes cost prohibitive, exceeding $180,000 per parcel in every sub-basin. The total cost of providing mitigation for all 451 property owners in the Skagit Basin jumps from $3.9 million for indoor only use to $83.4 million when outdoor use is added.

If both indoor and outdoor uses are sought for all properties, piped mitigation water is significantly more cost effective (e.g., as low as $11,000 per parcel) compared to trucking.

Additional considerations

Treatment

Drinking water is treated with chlorine to ensure it does not have microbiological contaminants. Chlorine cannot be discharged directly into the environment, either to surface or groundwater. As trucking water for mitigation would most likely involve using treated drinking water to provide mitigation, additional treatment to remove chlorine would be required to meet water quality discharge requirements. These costs have not been included in the cost estimates and they could be significant.

Operations and maintenance

The release of water into streams would need to be managed by an entity, and there would be associated ongoing costs in perpetuity. Potentially, Skagit PUD or another public entity could take responsibility for operations and management. However, a new entity may need to be created for long term operations and maintenance, such as a utility district or local improvement district. If an existing purveyor would take on responsibility for operating the system for mitigation, it would have to adjust water system planning documents, evaluate rates and staffing, and review existing water rights.

Environmental concerns

Large capacity water trucks (over 4,000 gallons) would have difficulty navigating in some areas, and local residents may object. Environmental impacts (noise, exhaust, etc.) from trucking were not factored into this analysis. Additional impacts from large, heavy trucks on roads, and added cost of road maintenance were not factored into this analysis.

Limitations on analysis

Additional detailed analysis with actual costs versus planning level (modeled) costs would be needed to get at precise costs. Actual cost would also depend on augmentation points within each sub-basin.

Using Winter Flow Capture to Mitigate for Stream Flow Impairment

WSU considered conducting a basin-scale analysis of ideal locations for capturing high winter stream flows for augmenting later summer/fall low flows. This approach was discarded when they determined landowners may be unwilling to build a pond. Time constraints on this study also did not allow for an in depth basin-wide scoping of locations. Instead, WSU used a parcel with an identified willing landowner in Child’s Creek basin (Hanson Creek HUC) to assess whether this alternative would be the lowest cost option for some of the parcels affected by the 2013 rule amendment repeal.

For ease of calculation, WSU estimated that constructing a pond to capture and store winter high flows would need to provide mitigation for 10 parcels. WSU assumed a larger pond capacity (double the size needed for mitigation), based on evapotranspiration loss and other efficiencies.

Costs

Assuming *indoor use only*, WSU estimated costs for constructing a pond that would provide mitigation to be $8,848 for each of ten parcels sharing a pond size of 2 acre-feet of storage. (This option must hold a larger amount of water for a longer period of time, making use of a cistern impractical.) This is not the most cost-effective option for most properties. However, compared with piping and trucking, storing water captured from high winter stream flows by constructing a pond could be a cheaper option for some of the more remote locations. Costs and other feasibility issues depend on a number of factors related to soil type, terrain, and climate.

Additional considerations

Additional detailed analysis would provide more accurate estimates of likely costs versus WSU's planning level (modeled) costs provided in their analysis.

For many locations, the key limitation for feasibility of this approach would be landowner willingness to participate. One or more landowners in each basin would need to have a large enough parcel to construct a pond that would preclude other uses for that part of their property. They would also need to maintain the pond and manage both the high flow capture, as well as the releases during low flow periods.

Costs were not estimated for using land owned by Skagit County. If Skagit County acquired land to build and manage a pond, those costs would make this option more expensive.

Treatment

Even though winter flow capture would not be treated with chlorine, it may require some type of treatment to meet water quality standards for temperature prior to release into a river or stream.

Operations and maintenance

The release of water into streams from a pond or storage reservoir would need to be managed by an entity (either public or private), and there would be associated ongoing costs in perpetuity. A new entity may need to be created for long term operations and maintenance, such as a utility district or local improvement district. If an existing purveyor were to take on responsibility for operating the system for mitigation, it would have to evaluate rates and staffing.

Limitations on analysis

Additional detailed analysis with actual costs versus planning level (modeled) costs would be needed to get at precise costs, including the cost of easements. Actual cost would also depend on augmentation points within the sub-basin.

Conclusions

Providing mitigation water to recharge groundwater or augment streamflows using effectively sized storage could be accomplished using small-scale piping, trucking, or winter flow capture. Water would be stored and then be released to recharge shallow aquifers or directly into streams in the summer months, mitigating the impacts from the use of permit-exempt wells.

The feasibility of the options is related directly to costs, but must consider other factors, such as long-term operation and management, and environmental concerns.

Costs

Costs vary greatly depending on the approach (piping, trucking, or winter flow capture), location within the basin, and the number of affected parcels within a particular sub-basin. The costs identified in the study are planning-level estimates based on modeled results and assumptions; actual costs will depend on site-specific details. Table 5 and Figure 5 summarize WSU's estimates of the least cost option for each sub-basin for indoor use only.

The cost estimates provided in this report for providing mitigation water in the Skagit Basin are generally much higher than the costs of mitigation elsewhere in the state, which rely on water banks. Water banks around the state do not rely on the mitigation options studied by WSU in this study. Instead, the water banks rely on purchases of senior water rights, which are then retired through the Trust Water program. A comprehensive listing of all operating water banks in Washington is found on the Ecology website, at:
http://www.ecy.wa.gov/programs/wr/market/trk-wawtrbnks.html

Acquiring a senior water right and retiring that right is likely be the most feasible cost-effective approach for mitigation in the Skagit Basin for many of the affected parcels. However, Ecology has had limited success to date in finding senior water rights appropriately located to mitigate property owners' use of existing wells. WSU assessed alternatives that would provide options to sub-basins in which no better alternatives exist. Furthermore, the disparate costs of the options assessed in the WSU study gives further evidence that using a variety of mitigation strategies throughout the Skagit Rule area from the full suite of mitigation options developed may be needed to meet needs throughout the basin.

Indoor use only

- The mitigation cost per household ranges between $6,000 and $12,000 depending on the specific sub-basin.
- When only considering properties with houses constructed after 2001, trucking mitigation water is the least expensive mitigation option in most sub-basins.

- Incorporating future development beyond the 451 properties considered in this study will make piping mitigation water more competitive relative to trucking.
- Winter flow capture may be the least expensive option in some sub-basins, particularly for the more remote sub-basins.

Table 5. Least cost mitigation alternative by sub-basin, indoor use only.

Map Reference #	Sub-basin Name	Number of Homes/ Businesses	Least costly method (indoor use only)	Cost per Household/ Business
1	Aldon Creek-Skagit River	39	Winter Flow Capture	$8,848
2	Copper Creek-Skagit River	9	Winter Flow Capture	$8,848
3	Day Creek	3	Winter Flow Capture	$8,848
4	East Fork Nookachamps Creek	17	Trucking	$6,639
5	Grandy Creek	28	Trucking	$8,648
6	Hansen Creek	79	Trucking	$7,909
7	Joe Leary Slough-Frontal Padilla Bay	17	Trucking	$6,582
8	Lake Shannon-Baker River	1	Winter Flow Capture	$8,848
9	Loretta Creek-Skagit River	28	Trucking	$8,465
10	Lower Samish River	7	Trucking	$8,045
11	Mill Creek-Skagit River	52	Piping	$7,600
12	Nookachamps Creek	33	Trucking	$6,469
13	Prairie Creek-Sauk River	23	Winter Flow Capture	$8,848
14	Rocky Creek-Skagit River	7	Winter Flow Capture	$8,848
15	Sauk River	6	Winter Flow Capture	$8,848
16	Skagit Delta-Frontal Skagit Bay	94	Trucking	$6,190
17	Skagit River	1	Winter Flow Capture	$8,848
18	Stillaguamish River-Frontal Port Susan	7	Trucking	$7,970

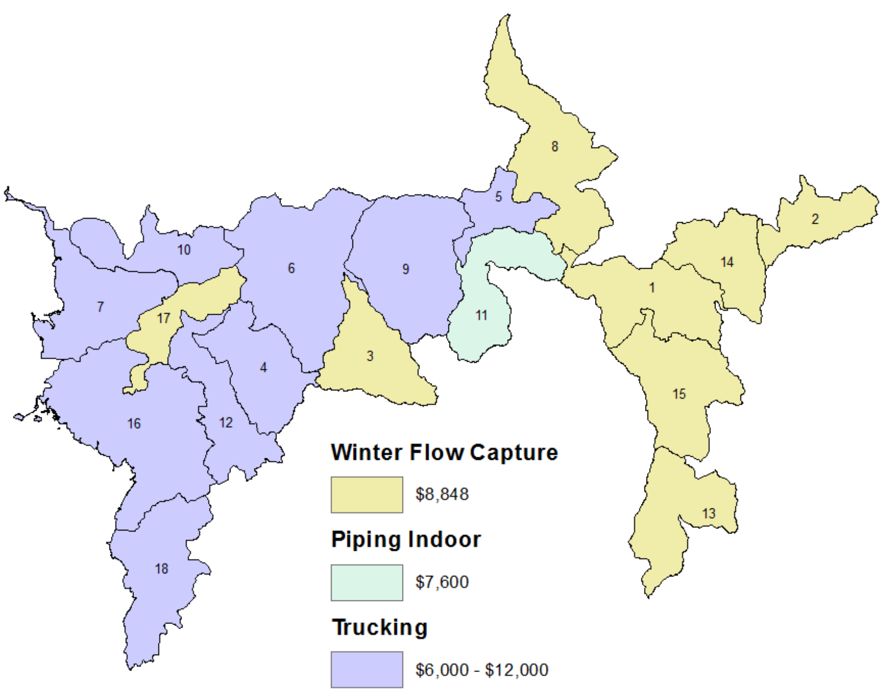

Figure 5. Least cost option by sub-basin assuming indoor water use only.

Indoor/outdoor use

- Trucking for mitigating indoor/outdoor use is not feasible because of the extremely high cost compared to piping mitigation water.
- Incorporating future development beyond the 451 properties considered in this study will make piping mitigation water more competitive relative to trucking.
- When considering both indoor/outdoor use, piping mitigation water is the least cost option (Table 6).
- Winter flow capture may be the least expensive option for the more remote sub-basins with only a few affected parcels.

Table 6. Least cost mitigation for 30 years of indoor/outdoor use – Piped.

Map Reference #	Sub-basin	Number of Homes/ Businesses	Cost per Household/ Business
1	Aldon Creek-Skagit River	39	$18,582
2	Copper Creek-Skagit River	9	$23,949
3	Day Creek	3	$121,383
4	East Fork Nookachamps Creek	17	$23,873
5	Grandy Creek	28	$25,803
6	Hansen Creek	79	$19,548
7	Joe Leary Slough-Frontal Padilla Bay	17	$16,904
8	Lake Shannon-Baker River	1	$91,693
9	Loretta Creek-Skagit River	28	$30,856
10	Lower Samish River	7	$13,593
11	Mill Creek-Skagit River	52	$10,687
12	Nookachamps Creek	33	$19,677
13	Prairie Creek-Sauk River	23	$102,913
14	Rocky Creek-Skagit River	7	$12,254
15	Sauk River	6	$54,844
16	Skagit Delta-Frontal Skagit Bay	94	$11,742
17	Skagit River	1	$26,849
18	Stillaguamish River-Frontal Port Susan	7	$50,965

Legal considerations

A water supplier may need to seek a change to their water right place and purpose of use. They may also need to update their comprehensive water system plan, and managing the larger service area may require additional staffing.

Potentially, the Legislature could ensure that litigation does not result, by providing clear authorization that inchoate municipal water rights could be used for mitigation purposes in the Skagit Basin.

Water quality

Whether piping, trucking, or capturing winter flow, additional considerations are required. There are water quality issues that need to be considered before water can be used for mitigation. Municipal water, whether trucked or piped, is treated with chlorine and other additives that are harmful to fish and aquatic life. Even captured winter flows may require additional treatment for temperature before release to the stream.

Funding considerations

During the public comment period for this report, Ecology received a request to identify key questions relating to mitigation funding options analyzed by WSU. The primary options for funding include:

- Legislative appropriation;
- Imposing fees on property owners benefitting from mitigation; or
- Charging all existing and future water users.

As there is a meaningful difference between parcels developed from 2001-2013 and future development, we identify funding options for each situation separately. Ecology does not endorse any specific option or approach for funding.

Funding options for parcels developed between 2001 and 2013

Legislative appropriation

The Legislature has appropriated $2.225 million to Ecology to acquire mitigation in the Skagit Basin. Ecology has obligated roughly $2 million of that total for acquisition of water rights, developing a water banking administrative structure, and evaluating water storage options associated with shallow aquifer storage (as discussed in the WSU report). The total cost for mitigating all 451 parcels exceeds the remaining funds under existing legislative appropriations. The Legislature could choose to appropriate additional funding to cover the costs associated with mitigation, or appropriate funding to partially pay for mitigation, with the remainder being funded through imposition of fees.

Imposing a fee on property owners that benefit

Imposing fees on existing property owners would be difficult to initiate and administer. First, it would be administratively challenging to impose fees on existing developed property owners that have an uncertain supply of water. There is no clear legal authority nor mechanism for Ecology to collect the fees.

Second, these residents built their homes under the presumption that they had legally available water. In addition, their land use permits were not challenged when development occurred. Therefore, retroactive fees could be challenged on constitutional grounds.

Funding options for future development

Legislative appropriation

The amount of additional appropriations needed to cover costs for new development are uncertain and substantial. Because costs are so basin specific, extensive additional analysis would be necessary before these costs could be quantified specifically. Based on the cost estimates for the existing 451 parcels, funding additional undeveloped property is unlikely to be feasible.

Imposing a fee on property owners that benefit

Imposing a one-time fee that is collected when a building permit application is made could fund the cost of mitigation. This fee could be collected by the County, which would be an efficient administrative mechanism, and is supported by existing legal authorities.

Alternatively, an annual fee could be assessed on property owners, and administered through the property tax system. This approach would require all future households and businesses that use water in the Skagit Rule area to pay an annual mitigation fee to offset their water use.

Charging all existing and future water users

An annual fee could be developed by Skagit County and assessed on all property owners in the Skagit basin. It could be administered through the property tax system, or some other mechanism used by the County, such as one analogous to a stormwater utility. Because the cost of mitigation would be spread among all households in the affected area, the amount charged per household or business could be relatively small. In addition, collection of the fee through an existing county collection system would have a lower administrative burden.

Next Steps

This study focuses on a subset of mitigation options for the Skagit basin. As this study shows, mitigation options and costs are very location-specific. Better understanding of options for a given area can only come from doing more site-specific analysis.

If the Legislature directed and funded Ecology to evaluate the trucking and piping mitigation approaches in more detail, it may be possible to determine how best to ensure long-term operations and maintenance. In addition, other environmental concerns, including impacts on air quality, would have to be addressed before trucking is used broadly throughout the basin.

There is also uncertainty with using inchoate municipal water rights for mitigation purposes. To address this uncertainty, Ecology recommends that clear authorization be adopted into statute before inchoate municipal water rights are used for mitigation purposes in the Skagit Basin.

If the Legislature chooses to further explore options presented in this report, we recommend they fund and authorize a pre-engineering level assessment to refine costs and feasibility. Specifically, Ecology recommends further assessment on the viability of piped water mitigation in the Skagit/Delta-Frontal sub-basin, which includes the Carpenter and Fisher Creek drainages. This recommendation is based on:

- This sub-basin is in the lowest cost category, so it is the most cost effective of any of the sub-basins analyzed by WSU.
- The total cost of mitigating existing water users in this basin is estimated at about $1.1 million.
- Piped water becomes more cost effective over time as more development occurs and more property owners share in the capital cost outlays to construct the basic infrastructure.
- The density of the existing homes without a legal water supply is high.
- The basin has the highest likelihood of future development significantly impacting stream flows.
- A successful piped water mitigation project in these sub-basins could be extended to the adjacent Nookachamps Creek headwaters, another area of significant demand.

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Appendix A

Skagit Basin Water Mitigation Feasibility Assessment

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Skagit Basin Water Mitigation Feasibility Assessment

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Table of Contents

1 Overview

The Skagit River Basin Instream Resources Protection Program Rule (WAC 173-503) of April 2001 established an instream flow rule for the Skagit River. A 2006 Department of Ecology amendment to this rule provided additional reservations for groundwater use in some subbasins. Based on these reservations, over 400 residential properties were developed in the subbasins with the expectation of an exempt well water right. In 2013, the Washington State Supreme Court ruled that these water reservations were invalid, and any well drilled since April 2001 is invalid and subject to interruption (http://bit.ly/2ejcDkT). The implication of this ruling is that these properties no longer have a secure, uninterruptible, water right and thus need in-place and in-kind mitigation. To date, only one mitigation alternative for a small development has been deemed amenable to all interested parties. This has negative consequences for current owners of the relevant properties, so there is a need to explore mitigation alternatives for real estate properties in the Skagit Basin that are currently without a legal water right due to this ruling. The closure to additional groundwater wells also restricts the potential for future development, so viable mitigation strategies are necessary for future development in the basin as well.

Engrossed Senate Bill No. 6589 (http://bit.ly/WASB6589) charges the Department of Ecology "to examine the feasibility of using effectively sized water storage to recharge the Skagit River Basin when needed to meet minimum instream flows and provide non-interruptible water resources to users of permit exempt wells within the Skagit river basin." This report has been funded through the State of Washington Water Research Center and Washington State University under contract with the Department of Ecology to satisfy this responsibility.

The objective of this study is to identify the least cost mitigation option in a spatially explicit manner for all of the properties whose groundwater rights were invalidated by the 2013 Supreme Court ruling. This analysis builds on previous studies to the greatest extent possible in order to avoid duplication and redundancy. The report complements previous research by focusing on two options to mitigate against groundwater use options through flow augmentation or aquifer recharge: piping and trucking. In contrast to piping and trucking for direct use to homes, piping and trucking for mitigation delivers water to a limited set of augmentation locations on Skagit River tributaries to mitigate against nearby residential exempt well use.

Mitigation costs were examined using spatially explicit data on the location of invalidated wells, existing PUD piping, roadways, information about requisite augmentation needs, river tributary characteristics, topography, and related cost information. Because property-specific mitigation costs vary by location for each mitigation option, the lowest-cost option may vary depending on location.

The core analysis focuses on piping and trucking water for streamflow augmentation, but we provide coarse comparisons to other alternatives, such as storage reservoirs for winter flow capture, trucking and piping for direct consumption, and rainwater capture based on information from existing studies. Further, while we focus on mitigation for the 451 properties developed since April of 2001, we provide several general results relating to water provision for future development in the otherwise closed sub-basins.

Key Findings:

- Focusing on the cheapest mitigation option where indoor use only is permitted, the mitigation cost per household ranges between $6,000 and $12,000 across the subbasins.

- When only considering properties with houses constructed after 2001, trucking is the cheapest mitigation option if indoor use only is considered.
- Winter flow capture may be the cheapest option for a few of the more remote subbasins.
- Adjusting cost estimates with hypothetical future development makes piping more competitive relative to trucking.

The study area is shown in Figure 1. The red areas are the affected properties. The boundaries of the HUC-12 watersheds within the Skagit River Basin are shown along with (blue) the major tributaries of the Skagit River. The designation "HUC" is an acronym developed by the United State Geological Survey which stands for Hydrological Unit Code.

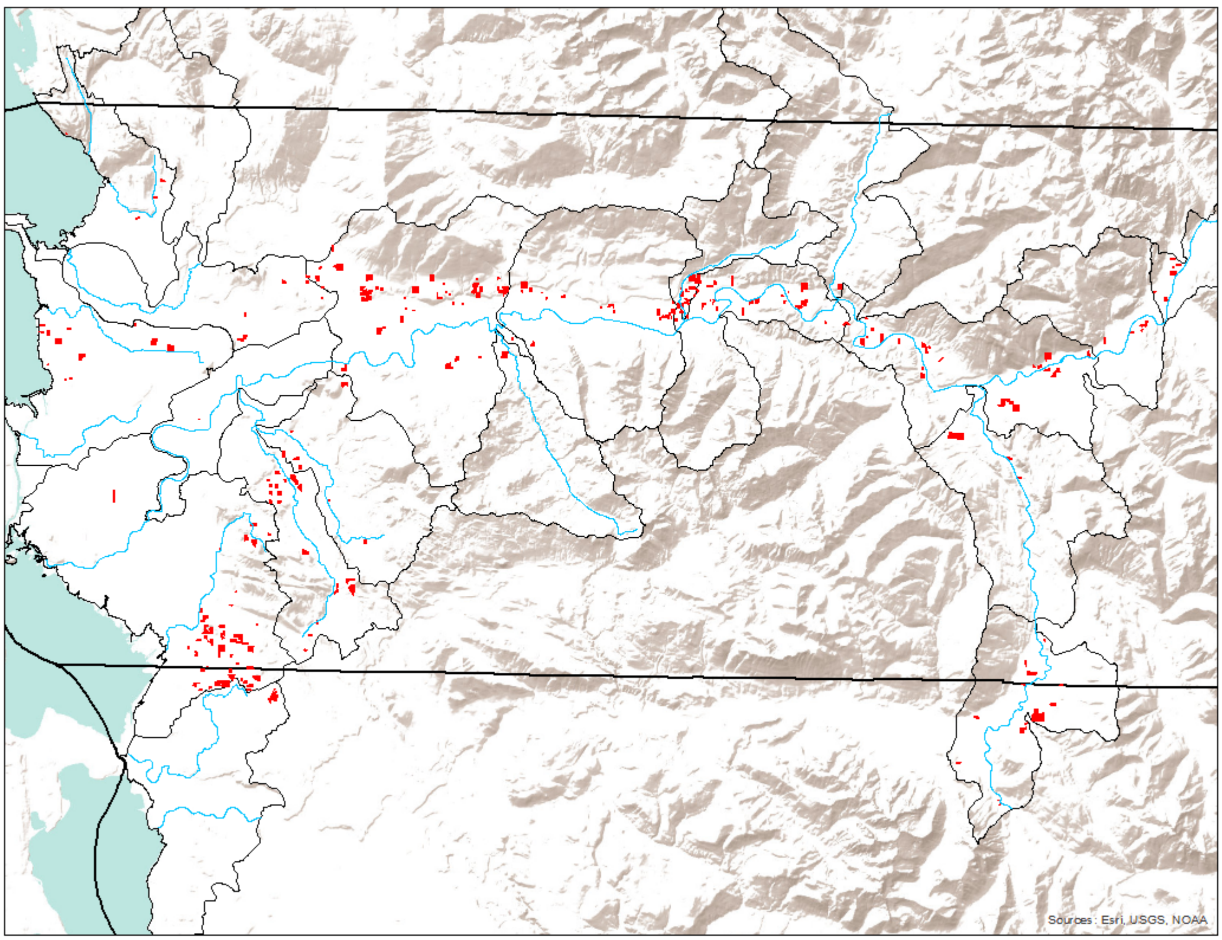

Figure 1. Skagit Basin with build properties in red, HUC-12 watershed boundaries in black, and Skagit Mainstem and tributaries in blue.

The next section provides a summary of previous studies of mitigation options for the Skagit basin. Section 3 describes fundamental assumptions about per-household mitigation needs, Section 4 summarizes methods and provides results for piped flow augmentation, Section 5 summarizes methods and provides results for trucking water for flow augmentation, Sections 6 and 7 briefly discuss surface storage and rainwater collection alternatives, Section 7 provides an integrated analysis of results trucking and piping for flow augmentation. Conclusions are provided in Section 8, followed by references and technical appendices.

2 Previous Studies

A range of scenarios that could potentially provide the Skagit properties with a legal uninterruptible water right have been considered and discussed in previous reports.

Under SB 5965 (session year 2015), Ecology authored a review of Skagit water supply options (Dept of Ecology, undated draft). The review focuses on 1) extension of public water systems for direct use, 2) rainwater collection/trucking, 3) building in areas not in hydraulic continuity with the Skagit River, and private mitigation plans. The review reports that trucking costs per household "range from $25,000 for an indoor only system to $260,000 for a system capable of irrigating up to 10,000 square feet". These costs are in present value terms, so they represent the one-time cost to the household. In addition to cost, DOH regulations and the willingness of banks to lend to properties with cistern-based water systems are identified as obstacles.

RH2 Engineering (2014) considered the feasibility of extending existing public water systems directly to properties as a replacement for wells. In addition to providing cost estimates this report addresses an important legal issue that is relevant to this study in regards to municipal inchoate rights as a mitigation source. As stated on page 4 of said report, inchoate water rights found to be in good standing can be "transferred" to be integrated into a regional water system. A color coding system is used to categorize the standing of municipal inchoate rights. Tatoosh Water Company has been given a blue rating by DOH which means that it is not adequate for adding new service connections. Expansion would require a new Comprehensive Water System Plan. Also discussed in the report is the issue of leakage, which is substantial at close to 50%. Tatoosh's water right allows for a maximum withdrawal of 1,135 acre-feet of water. The maximum over a 12-year period starting in 2000 was 112.1 acre-feet. Additional discussion of this report is provided in Section 4.1.

A project that received significant attention considered the use of wetlands restoration for water storage. The reports summarizing this project also provide discussion of legal issues relevant to this study (Associated Earth Sciences, Inc., 2014). Specifically, whether Upper Skagit Indian Tribe (USIT) needs a permit to divert or store water for mitigation.

The potential to rely on reclaimed water for instream flow mitigation has also been considered in collaboration with Skagit County Sewer District No. 2 in the Nookachamps Creek Basin. The idea behind the approach is that flows in the Nookachamps Creek can be augmented by reclaimed municipal water in a way that mitigates for wells in the basin. Estimates of total costs for the project range between $10 and $14.2 million.

3 Household Water Use Assumptions

Water use in households relying on groundwater wells is poorly monitored (few properties are metered). From the data that are available, there is variation across households. In the best case scenario one would have metered data for all properties. A study was performed by Golder Associates, Inc. (Einberger, C. et. al., 2014) in Skagit County where well water use was metered for 18 houses. Water use ranged from 56 to 456 gpd. The average across all properties was 175 gallons per day. An attempt was made to separate indoor use by looking at the average for the year after removing peaks in the summer months. The study found that there was no apparent outdoor water use for 7 of the 18 properties. Their estimate for the range of indoor use was 41 to 289 gpd with an average of 131 gpd. Outdoor use averaged at the household level over the entire year ranged between 6 and 112 gpd, with an average over households of 56 gpd.

These estimates are lower than assumptions/estimates made for rural residential properties affected by the moratorium on permit exempt wells in Kittitas County. For example, Haller (2015) recommended assuming indoor use to be 275 gpd (Haller, 2015). Taking information from Einberger et al (2014), Haller (2015), Ecology (2015), and discussions during stakeholder meetings for this project, we assume for the remainder of this report that consumptive use per year is 0.02 ac-ft, which is between 17 and 18 gpd, for indoor use. This corresponds to an assumption that about 90% of withdrawals flow back into surface or groundwater. The consumptive use for both indoor and outdoor use is assumed to be 0.1ac-ft or 90 gpd. Figure 2 helps to visualize these flows.

In this study, we assume that the households must mitigate to compensate for their full annual consumptive use. This is likely to over-mitigate relative to actual impacts on critical instream flow deficits. Low flows are generally seasonal and do not extend over the entire year. However, the complexity of ground and surface water continuity and timing of flows makes it difficult to defend partial-use mitigation.

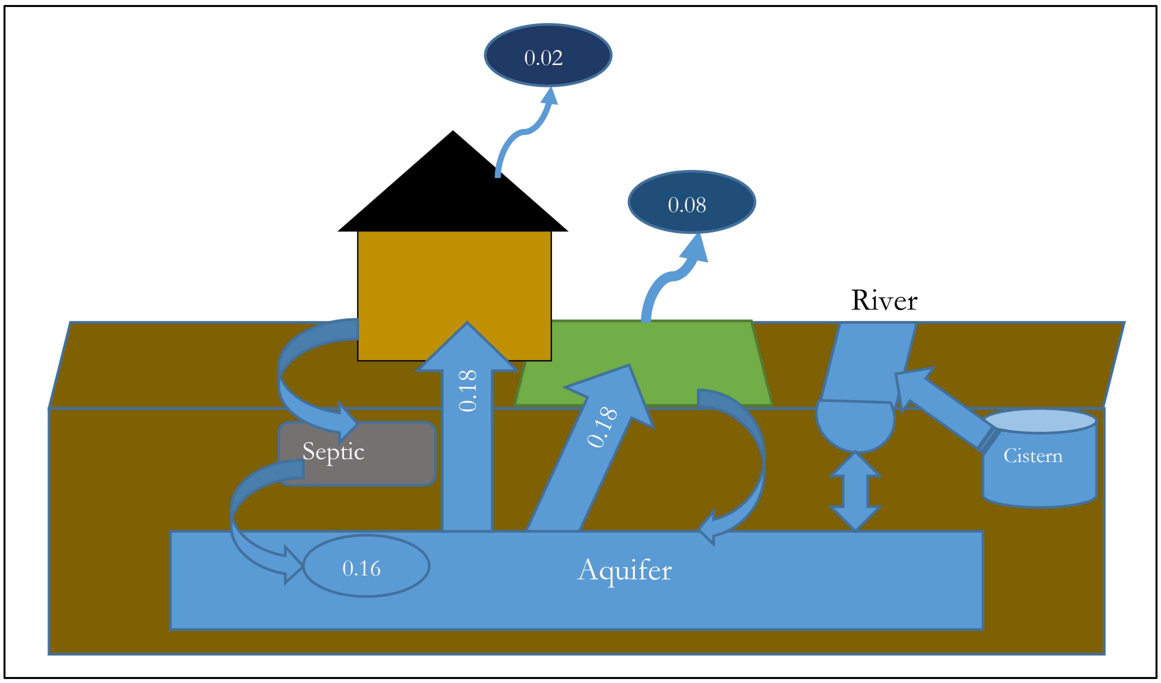

Figure 2. Assumptions on water diversions and consumptive use in acre-feet per year.

4 Piping for Mitigation by Flow Augmentation or Aquifer Recharge

The extension of pipelines from existing PUD systems for flow augmentation or aquifer recharge is an alternative to the more conventional approach of directly connecting properties PUD water service to replace wells. In contrast, our modeling is based on the idea of extending small gauge pipes from public water systems for the purpose of mitigation such that properties would continue to use their wells.

The potential cost reduction relative to direct home connection comes from three factors. First, smaller pipes can be used because only the consumptive use portion needs to be piped rather than direct use. Second, variable costs associated with transporting water are lower for mitigation compared to direct use because much less pressure is required and additional concerns related to human health are not a factor. There are water quality issues related to environmental health that do need to be considered for mitigation. Third, it is probable that a greater distance of pipelines would be needed for direct connection because they have to get to every property. In contrast, it may only be necessary to extend pipes to a single augmentation point in a subbasin, thus reducing the total distance piped.

This section proceeds as follows. We first provide a detailed summary of a previous analysis that modeled the extension of a public water system for directly connecting to properties so that they stop using wells. We then provide a detailed summary of how the modeling was done. Results in terms of cost per house by subbasin are reported. The final sub-section provides a close-up visual summary of how the piping is done in one subbasin.

4.1 Review of Public Water System-Based Scenarios from Previous Studies

A brief summary of a detailed study on direct connections is useful in providing reference points to the piping for augmentation modeling done as part of this project. RH2 Engineering (2014) analyzes a mitigation strategy in which the Tatoosh Water Company would expand to provide direct connections to properties affected by the 2001 decision. The Tatoosh Water Company has both excess capacity in terms of pumps and pipelines, as well as inchoate rights that could be used for mitigation. Two water right certificates, both with a priority date of 5/20/1971, were interpreted by RH2 to have a total annual permissible quantity of 1,135 acre-feet/year, or 1,550 gpm. The current Tatoosh systems is approved for 116 connections. Data on annual withdrawals for the system show an average annual withdrawal of 78.3 acre-feet/year. The maximum over this time period was for 2007 when 112.1 acre-feet was used. Tatoosh Water Company does acknowledge that about half of the water pumped is lost due to leakage. In 2011, 81.8 ac-ft/year was produced and purchased while 41.9 ac-ft/year were lost to leakage.

RH2 Engineering (2014) considers alternative ways to use the Tatoosh water right to provide water to affected properties. Option 1a uses Lake McMurray as a storage system that could receive water from the Tatoosh pumps in a way that augmented flows downstream in the subbasin. A number of important implementation details are considered including the pathway for the pipeline, a possible augmentation point, and alternatives for building off of the existing public water system (PWS). Option 1b focuses on extending the PWS mainlines to directly connect properties, in particular those on the west side of Lake McMurray. It is assumed that a 12-inch-diameter pipe is used.

Context on two potentially complicating factors discussed in RH2 Engineering (2014) is relevant for the piping scenario in this present study. First, uncertainty over groundwater flows are recognized. Even in the case of only considering one subbasin (Upper Nookachamps) there is recognized uncertainty as to whether augmenting at one location provides in-place mitigation for some properties in the same subbasin. Clearly, there is a need for further analysis of groundwater flows and the nature of hydrologic connectivity to households in some subbasins.

Second, the reliance on inchoate rights and infrastructure from a PWS, whether it is Tatoosh or Skagit PUD, requires a willingness on the part of these service providers to expand their scope of service. Tatoosh would need to update their comprehensive water system plan to include properties that are currently on wells. In this report we do not explicitly consider the additional burden placed on Tatoosh Water Company or Skagit PUD, but simply recognize here that the scenarios considered would represent new tasks for these companies that would likely require additional resources.

A breakdown of costs for Options 1a and 1b are provided in Tables 20A and 20B, respectively (RH2 Engineering, 2014). Option 1a is estimated to cost between $1.22 and $1.49 million, while Option 1b's cost estimate ranges between $5.2 and $6.4 million. In both cases the single largest cost item is the piping. For 1a the 8" pipe cost is $120/foot. The 12" pipe for 1b costs $150/foot. In this study we are assuming much smaller pipes, typically 1", that are under much lower pressure. The smaller gauge and different type of material are the primary driver of the differences in cost. The assumed cost per foot for the 1-inch pipe assumed in this study is $38. The RH2 report does not specify a cost per household. This is in part because the report was aimed at considering the potential to supply water for future development, which is uncertain. However, to get a sense of the cost per household one could divide total cost by the number of properties built after 2001 in the subbasin. There are 33 properties in the Nookachamps Creek subbasin, so dividing $1.2 million by 33 gives, $37,000, which is the lowest of Options 1a or 1b. As is discussed later in this report, the switch to a smaller gauge pipe made possible by assuming that only consumptive use is mitigated for reduces costs by more than a third.

4.2 Data for Pipe Path Modeling

A number of GIS data sets were needed to identify optimal pipe paths between public water systems and rivers. Table 1 provides the source location for the datasets used to estimate the distance between existing municipal systems/sources and augmentation points on a HUC-12 mainstem:

Table 1. GIS data sources for municipal pipeline extension modeling.

Data Description	Online Location
DEM elevation	National Hydrography Dataset http://www.horizon-systems.com/nhdplus/NHDPlusV1_17.php
Flowlines	National Hydrography Dataset http://www.horizon-systems.com/nhdplus/NHDPlusV1_17.php
Flow accumulation	National Hydrography Dataset http://www.horizon-systems.com/nhdplus/NHDPlusV1_17.php
HUC-12 boundary	WA State Department of Ecology ftp://www.ecy.wa.gov/gis_a/inlandWaters/waterdiversions.zip
Skagit PUD mains	WA State Department of Ecology *Personal communications*
Tatoosh Water Co. mains	WA State Department of Ecology *Personal communications*
Parcels without water right	WA State Department of Ecology *Personal communications*
Roads	Skagit County Geographic Information Services http://www.skagitcounty.net/Departments/GIS/Digital/streets.htm

4.3 Identifying Augmentation Points

Given that there are an infinite number of points to which pipelines could be extended it was necessary to develop a rationale for only looking at a limited number of points. The key decisions made were:

a. In piping for flow augmentation the analysis primarily considers a single pipeline extending to a river for each subbasin.
b. Use HUC-12 subbasins as the unit of analysis. Properties are scattered throughout the entire basin so it is valuable to find a way to break apart the larger region into smaller units that are treated as hydrologically independent.
c. Augmentation would be applied only to the mainstem of the tributary. It is possible that critical minimum flow issues are on subtributaries, but these are not considered.
d. The augmentation point is a location on the tributary nearest to the most upriver house in the subbasin.

4.4 Cost Assumptions

Piping cost assumptions can be separated into fixed and recurrent (sometimes referred to as variable) costs. Fixed costs include the pipeline, which is a function of the pipeline length and diameter, and infrastructure at the augmentation point for storing and treating water before it is released. Recurrent costs include the utility charge for pumping water. It is also necessary to capture the fact that the piping infrastructure degrades over time. One way to account for this is to include repair and maintenance costs. An alternative approach is to assume that the infrastructure has a limited lifespan and will need to be replaced. We used the latter approach. Details are provided below in the recurrent cost assumptions section.

The following formulas were used to estimate the piping costs. Piping costs decrease the smaller gauge pipe used, so the minimum pipe diameter is calculated with the formula below. The water flow velocity (V) is assumed to be 5 ft/second (WSU, 2016):

V = water flow velocity inside the pipe assumed to be 5 ft/second = $0.408x(Q/D^2)$
Q = flow rate of water inside pipe (gpm) which is based on the assumption of household use
D = pipe inside diameter = $[(0.408 \text{ x } Q)/V]^{1/2}$

Fixed Cost Assumptions

- Pipeline length represents the pathway between existing utility infrastructure and a stream augmentation point with the smallest slope. The cost of the pipeline and installation was estimated to be $200,000/inch-mile.

- Pipeline diameters available are either 0.25", 0.5", 0.75" or 1" (inner diameter). The diameter selected for a basin depends on the volume of water required. For most subbasins the assumption on pipe diameter was about 50% larger than the calculated minimum pipe diameter. This is a result of rounding up to the nearest 0.25".

- The formula for calculating total fixed costs for each subbasin is:
  Fixed costs = ($200,000 x Distance)/(1,600 x Pipe diameter)

Recurrent Cost Assumptions:

- Utility pumping charges were assumed to occur when water needs to move uphill to reach the augmentation point some distance away. In these cases, it was assumed that the cost to lift one acre-foot of water 1 foot in elevation is $0.17 (Skagit PUD, personal communication). Annual pumping costs are calculated using the formula:

Annual pumping cost per subbasin = Quantity of water x Elevation change x $0.17

- Utility water charges were assumed to be similar to those used in the 2015 Ecosystem Economics report, which are representative of a "retail" price. We assume a retail price rather than a wholesale price under the assumption that this is the more relevant opportunity cost for them using their inchoate rights for mitigation rather than future direct service to new customers. They are as follows:
  - Monthly Fixed Charge: $21
  - Monthly Consumptive Block Charge:
    - Indoor only: $18
    - Outdoor and Indoor: $30
  - Total Utility Charges:
    - Indoor only: $473/year
    - Outdoor and Indoor: $661/year
- In order to convert recurrent costs into a single present value it is necessary to make an assumption on both the time horizon and the discount rate. A time horizon of 30 years was chosen because this is consistent with assumptions made on the lifespan of small gauge pipelines like those considered in this scenario. A discount rate of 5% is generally consistent with Federal guidelines.

4.5 Pathway Delineation Assumptions

The following assumptions were made throughout the piping modeling:

- Parcels are only mitigated within the HUC-12 basin in which they lie.

- The HUC-12 scale is sufficiently small such that augmentation can occur at any point within the sub-basin and fulfill mitigation needs for all the parcels in that basin.

- Mitigation activities are focused on the mainstem, and need not occur at the closest surface water body to a parcel.

- The volume of water delivered at a given augmentation point on a mainstem will be equivalent to the sum of all the mitigation needs required for parcels within the HUC-12.

4.6 Mainstem Delineation

This study assumed that mitigating along the mainstem is sufficient to meet in-stream flow needs. Therefore, mainstem features in each HUC12 were identified using flow accumulation estimates and flowline features reported in the National Hydrography Dataset (for source data, see Table 1). The NHD flowlines overlapping the greatest flow accumulation pathway were assumed to be the mainstem in each basin (Figure 3). Each mainstem flowpath was assigned a FlowID value for reference purposes.

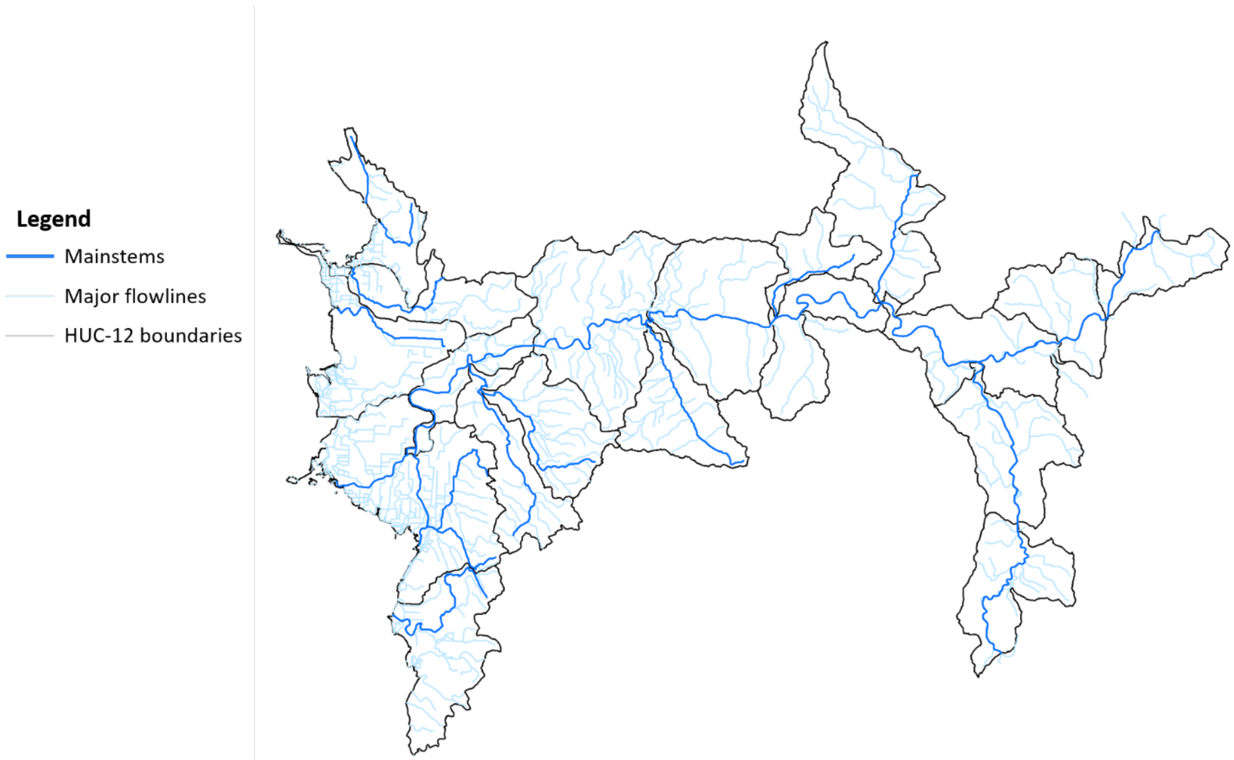

Figure 3. Mainstem and major flowline features within each HUC-12 sub-basin.

4.7 Piped Distance Model

A model was created in ArcGIS 10.2.2 to estimate the length of pipe required to deliver water from an existing municipal system to an augmentation point on a HUC12 mainstem (Figure 3). The model used in all three of the approaches below is designed to find the least cost pipe pathway between a given municipal system and a specific point on a stream.

Elevation and road location data were used to identify preferential pipe pathway options for any given augmentation point. Elevation data were used to calculate the slope between the system and augmentation points. Pathways with the smallest slopes, and therefore lowest pumping costs, were weighted preferentially (reclassified by quantiles to fit a scale 1-10). Roads were scaled preferentially based on their type classification (County and State = 1, Interstate = 2, Private = 10). Road values were weighted more heavily (75%) than slope (25%) to reflect preferential pathway options. The least accumulative cost distance (based on these weighted slope values) between the two points of interest was calculated to create a cost surface. These data were then used to calculate the least-cost path between the given municipal and stream augmentation points. This is the pipe distance used to calculate augmentation costs. A more technical description of the process is provided in the Appendix (Section 10).

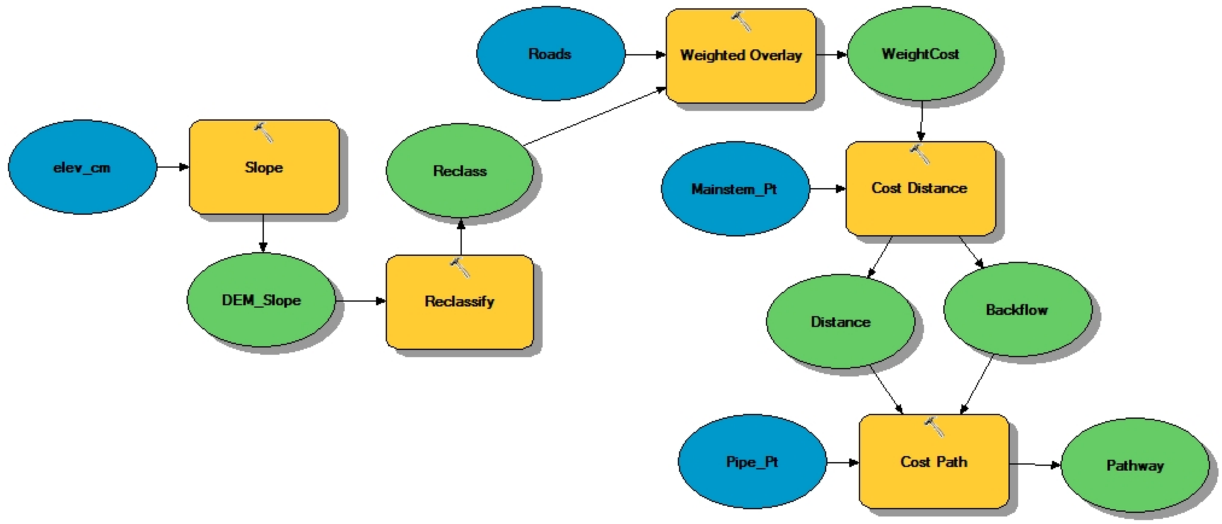

Figure 4. Piped distance model. This model shows the data (blue), tools (yellow), and outputs (green) used to calculate the pathway between a given municipal pipe point and stream augmentation point that has the smallest slope.

Least Cost Approach

The least cost approach minimizes the piping distance to a subbasin augmentation point, which is equivalent to minimizing piping costs. In this approach, augmentation occurs where the HUC-12 mainstem is closest to an existing municipal piped infrastructure. This represents the shortest possible distance between the mainstem and a municipal system and makes no attempt to augment near a particular property where withdrawals are being made.

Highest Elevation Approach

Here, augmentation occurs on a mainstem at the point closest to the property with the highest elevation in the HUC-12 basin (one property per basin).

Most Upstream Approach

Here, augmentation occurs on a mainstem at the point closest to the Most Upstream property in the HUC-12 basin (one property per basin).

The results of the Highest Elevation and the Most Upstream Approach may differ if, for example, there is one household in the upper reaches of the subbasin mainstem, and another at a higher elevation but on the upper flanks of the basin downstream of the first house. In this case, the reference household is different, and the augmentation point will therefore differ.

These three strategies for augmentation site selection reflect tradeoffs between costs and mitigation coverage. Highest Elevation and Most Upstream Approaches will tend to require longer piping runs because piped water sources are low in the basin and will therefore tend to be more costly. However, these two alternatives will generally provide better coverage for properties in need of mitigation, particularly those higher up in the subbasins.

4.8 Results

Cost results for the Most Upstream Approach are reported in Table 3 and Table 4, which are for indoor only and indoor and outdoor mitigation, respectively (for brevity, we will refer to indoor and outdoor as "indoor/outdoor"). Additional columns in these tables report the key variables needed for making these cost estimates. The Most Upstream cost estimates per house for each subbasin are shown in map form in Figure 5 (indoor only) and Figure 6 (indoor/outdoor). Due to space limitations in the figures it is not possible to label the subbasins by their name reported in data files by the U.S. Geological Survey. Therefore, a reference number is assigned to each subbasin which corresponds to the numbers in the figures (Table 2). The cost per household is highly variable across subbasins because of differences in the number of properties being mitigated for and the piping distance. A direct examination of the effect of piping distance and number of houses on piping costs is provided in Section 7.1. Table 5 reports the cost per household by subbasin for all three augmentation points. These costs vary due to differences in elevation change and piping distance.

For the Most Upstream scenario, there are three subbasins where the cost per household is less than $10,000 for indoor use only. While only three subbasins, they contain roughly one-quarter of the households under investigation. There are no subbasins where costs are less than $10,000 for both indoor and outdoor use.

One way to interpret the difference in the costs across the piping scenarios is by examining where more detailed modeling could lower piping costs by identifying cheaper but still adequate augmentation points. For example, in Nookachamps Creek the Most Upstream scenario is $12,211 versus $7,749 for the Highest Elevation scenario. In contrast, subbasins like Rocky Creek-Skagit River have nearly the same lower and upper cost estimates, which might justify being conservative (in terms of assuring sufficient mitigation) by mitigating at the slightly more costly Most Upstream point in the subbasin.

Table 2. Reference number for each subbasins reported in figures.

Reference Number	Sub-basin
1	Aldon Creek-Skagit River
2	Copper Creek-Skagit River
3	Day Creek
4	East Fork Nookachamps Creek
5	Grandy Creek
6	Hansen Creek
7	Joe Leary Slough-Frontal Padilla Bay
8	Lake Shannon-Baker River
9	Loretta Creek-Skagit River
10	Lower Samish River
11	Mill Creek-Skagit River
12	Nookachamps Creek
13	Prairie Creek-Sauk River
14	Rocky Creek-Skagit River
15	Sauk River
16	Skagit Delta-Frontal Skagit Bay
17	Skagit River
18	Stillaguamish River-Frontal Port Susan

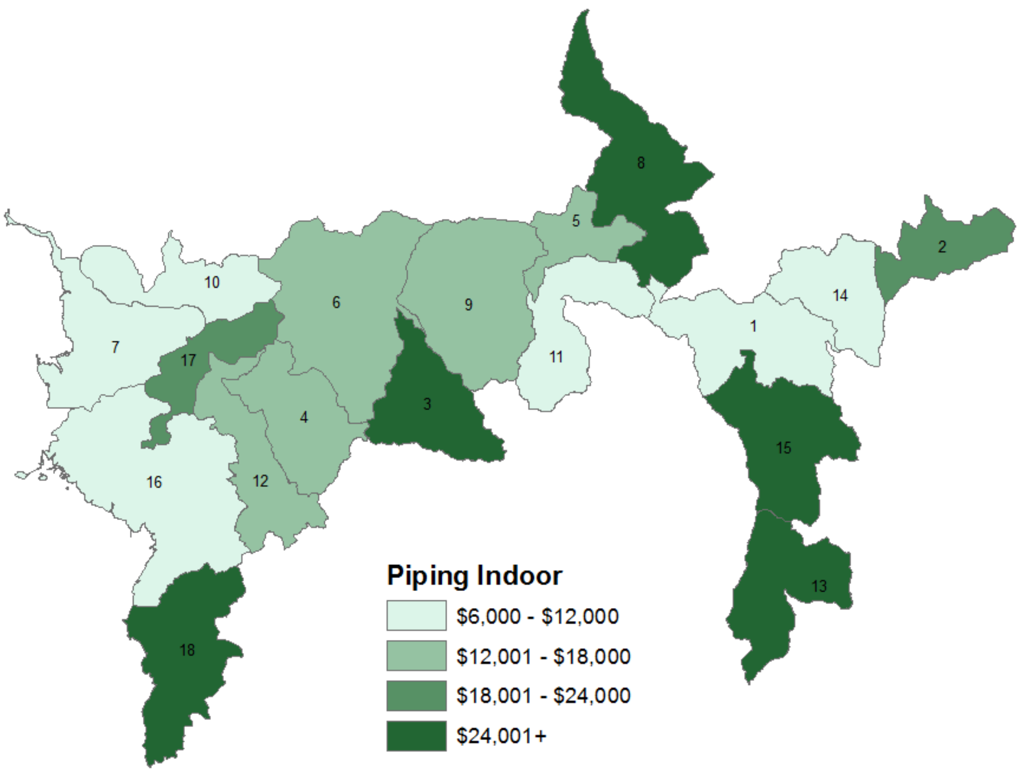

Figure 5. Upstream Approach - Indoor use only.

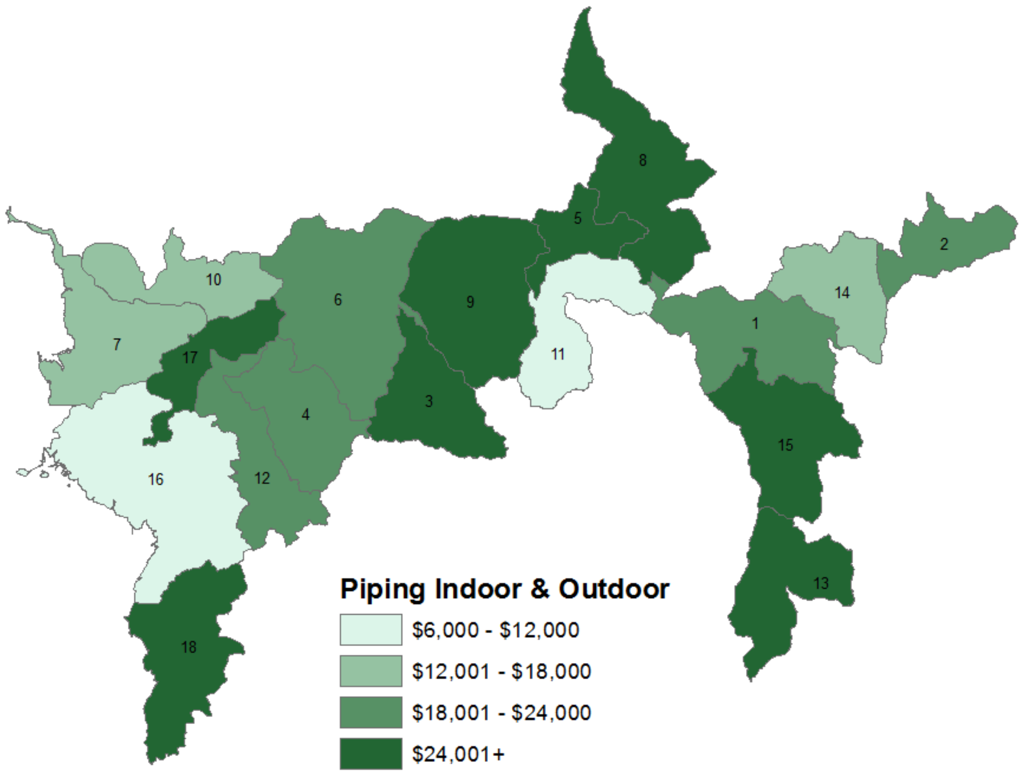

Figure 6. Upstream Approach- Indoor/outdoor use.

Table 3. Summary of piping cost estimate results for indoor use only.

Ref. #	HUC 12 Name	No. Parcels	Pipe distance (ft)	Elevation change (ft)	Water mitigation (af/yr)	Minimum pipe diameter (in)	Assumed pipe diameter (in)	Fixed costs	Total annual recurrent costs	30 yr present value of recurrent costs	Cost per household
10	Lower Samish River	7	1,261	5.3	0.14	0.084	0.25	24,011	3,311	50,900	10,702
7	Joe Leary Slough-Frontal Padilla Bay	17	5,388	-1.6	0.34	0.131	0.25	63,317	8,041	123,610	10,996
2	Copper Creek-Skagit River	9	11,764	17.7	0.18	0.095	0.25	124,049	4,258	65,449	21,055
8	Lake Shannon-Baker River	1	7,300	-38.6	0.02	0.032	0.25	81,531	473	7,271	88,803
14	Rocky Creek-Skagit River	7	278	-1.1	0.14	0.084	0.25	14,652	3,311	50,898	9,364
1	Aldon Creek-Skagit River	39	16,609	-29.5	0.78	0.199	0.25	170,202	18,447	283,576	11,635
13	Prairie Creek-Sauk River	23	111,244	348.1	0.46	0.152	0.25	1,071,603	10,906	167,655	53,881
15	Sauk River	6	26,882	26.3	0.12	0.078	0.25	268,054	2,839	43,635	51,948
5	Grandy Creek	28	22,285	196.2	0.56	0.168	0.25	224,268	13,263	203,880	15,291
11	Mill Creek-Skagit River	52	536	-58.6	1.04	0.229	0.25	17,110	24,596	378,101	7,600
9	Loretta Creek-Skagit River	28	29,788	-83.1	0.56	0.168	0.25	295,730	13,244	203,593	17,833
3	Day Creek	3	33,771	-427.3	0.06	0.055	0.25	333,667	1,419	21,814	118,493
6	Hansen Creek	79	25,529	4.7	1.58	0.283	0.50	498,322	37,368	574,442	13,579
4	East Fork Nookachamps Creek	17	11,557	212.5	0.34	0.131	0.25	122,077	8,053	123,799	14,463
12	Nookachamps Creek	33	15,854	-355.1	0.66	0.183	0.25	163,011	15,609	239,949	12,211
17	Skagit River	1	492	-4.2	0.02	0.032	0.25	4,688	473	7,271	23,959
16	Skagit Delta-Frontal Skagit Bay	94	4,218	-23.0	1.88	0.308	0.50	92,356	44,462	683,490	8,367
18	Stillaguamish River-Frontal Port Susan	7	28,699	145.9	0.14	0.084	0.25	285,362	3,314	50,952	48,045

Table 4. Summary of piping cost estimate results for indoor and outdoor use.

Ref. #	HUC 12 Name	No. Parcels	Pipe distance (ft)	Elevation change (ft)	Water mitigation (af/yr)	Minimum pipe diameter (in)	Assumed pipe diameter (in)	Fixed costs	Total annual recurrent costs	30 yr present value of recurrent costs	Cost per household
10	Lower Samish River	7	1,261	5.3	0.7	0.188	0.25	24,011	4,628	71,138	13,593
7	Joe Leary Slough-Frontal Padilla Bay	17	5,388	-1.6	1.7	0.293	0.50	63,317	11,237	172,740	16,904
2	Copper Creek-Skagit River	9	11,764	17.7	0.9	0.213	0.25	124,049	5,952	91,492	23,949
8	Lake Shannon-Baker River	1	7,300	-38.6	0.1	0.071	0.25	81,531	661	10,161	91,693
14	Rocky Creek-Skagit River	7	278	-1.1	0.7	0.188	0.25	14,652	4,627	71,128	12,254
1	Aldon Creek-Skagit River	39	16,609	-29.5	3.9	0.444	0.50	170,202	25,779	396,286	18,582
13	Prairie Creek-Sauk River	23	111,244	348.1	2.3	0.341	0.50	1,071,603	15,339	235,800	102,913
15	Sauk River	6	26,882	26.3	0.6	0.174	0.25	268,054	3,969	61,008	54,844
5	Grandy Creek	28	22,285	196.2	2.8	0.376	0.50	224,268	18,601	285,949	25,803
11	Mill Creek-Skagit River	52	536	-58.6	5.2	0.513	0.75	17,110	34,372	528,382	10,687
9	Loretta Creek-Skagit River	28	29,788	-83.1	2.8	0.376	0.50	295,730	18,508	284,513	30,856
3	Day Creek	3	33,771	-427.3	0.3	0.123	0.25	333,667	1,983	30,484	121,383
6	Hansen Creek	79	25,529	4.7	7.9	0.632	0.75	498,322	52,225	802,832	19,548
4	East Fork Nookachamps Creek	17	11,557	212.5	1.7	0.293	0.50	122,077	11,298	173,684	23,873
12	Nookachamps Creek	33	15,854	-355.1	3.3	0.408	0.50	163,011	21,813	335,319	19,677
17	Skagit River	1	492	-4.2	0.1	0.071	0.25	16,688	661	10,161	26,849
16	Skagit Delta-Frontal Skagit Bay	94	4,218	-23.0	9.4	0.689	0.75	92,356	62,134	955,152	11,742
18	Stillaguamish River-Frontal Port Susan	7	28,699	145.9	0.7	0.188	0.25	285,362	4,644	71,395	50,965

Table 5. Comparison of piping costs using different augmentation points in each subbasin.

Ref. #	HUC 12 Name	Indoor only Least Cost	Highest Elevation	Most Upriver	Indoor/outdoor Least Cost	Highest Elevation	Most Upriver
10	Lower Samish River	8,985	10,702	10,702	11,875	13,593	13,593
7	Joe Leary Slough-Frontal Padilla Bay	7,977	11,276	10,996	10,867	17,466	16,904
2	Copper Creek-Skagit River	8,917	22,324	21,055	11,807	25,219	23,949
8	Lake Shannon-Baker River	44,483	88,803	88,803	47,373	91,693	91,693
14	Rocky Creek-Skagit River	9,364	11,026	9,364	12,254	13,916	12,254
1	Aldon Creek-Skagit River	7,651	11,002	11,635	10,613	17,315	18,582
13	Prairie Creek-Sauk River	34,582	53,881	53,881	64,282	102,913	102,913
15	Sauk River	12,348	27,587	51,948	15,238	30,477	54,844
5	Grandy Creek	10,893	15,391	15,291	17,081	25,998	25,803
11	Mill Creek-Skagit River	7,578	7,621	7,600	10,621	10,749	10,687
9	Loretta Creek-Skagit River	17,859	22,456	17,833	30,909	40,105	30,856
3	Day Creek	107,023	118,493	118,493	109,914	121,383	121,383
6	Hansen Creek	7,423	13,411	13,579	10,313	19,296	19,548
4	East Fork Nookachamps Creek	7,977	9,306	14,463	10,867	13,524	23,873
12	Nookachamps Creek	7,635	7,749	12,211	10,525	10,755	19,677
17	Skagit River	19,271	23,959	23,959	22,161	26,849	26,849
16	Skagit Delta-Frontal Skagit Bay	7,399	NA	8,367	10,289	NA	11,742
18	Stillaguamish River-Frontal Port Susan	40,855	48,519	48,045	43,766	51,441	50,965

4.9 Implementing the Piping Option

To provide a better sense of how the piping scenarios is modeled we provide a more detailed summary of pipe paths and augmentation points for the area that drains into Carpenter and Fisher Creeks in the Skagit Front Bay HUC12 basin. These results are shown in Figure 7, Figure 8, Figure 9, and Figure 10. In all three scenarios, mitigation is focused on either the North or South Fork Skagit River. However, in the Least Cost and Most Upstream Approach, it was possible to extend additional analyses to Carpenter and Fisher Creeks in the Skagit Frontal Bay HUC12 basin (117100070204). These two creeks were selected because of their prominent and potentially important role in mitigation in other reports and studies. In these two scenarios, three augmentation points were assessed, one for the Skagit River, Carpenter Creek and Fisher Creek (Figure 8 and Figure 9). In comparing cost differences across these three potential points, the Skagit River is the least expensive point to augment in the Least Cost Approach, whereas Carpenter Creek is the least expensive option in the Most Upstream Approach.

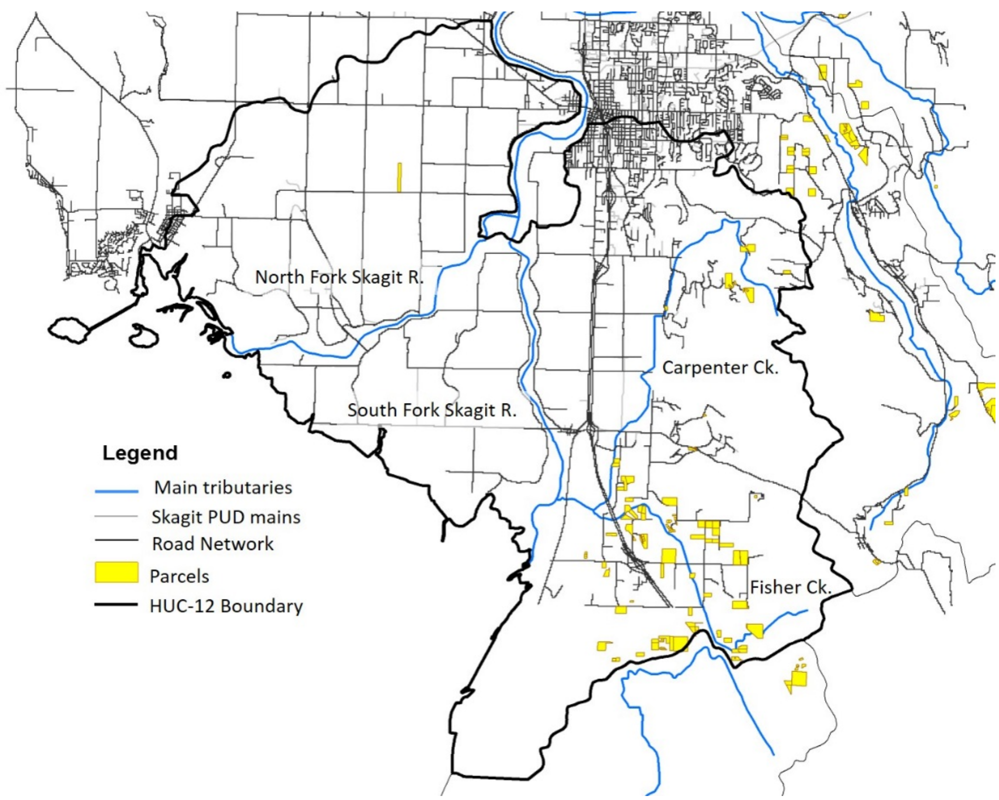

Figure 7. Base map features of HUC-12 Skagit Delta-Frontal Skagit Bay (171100070204)

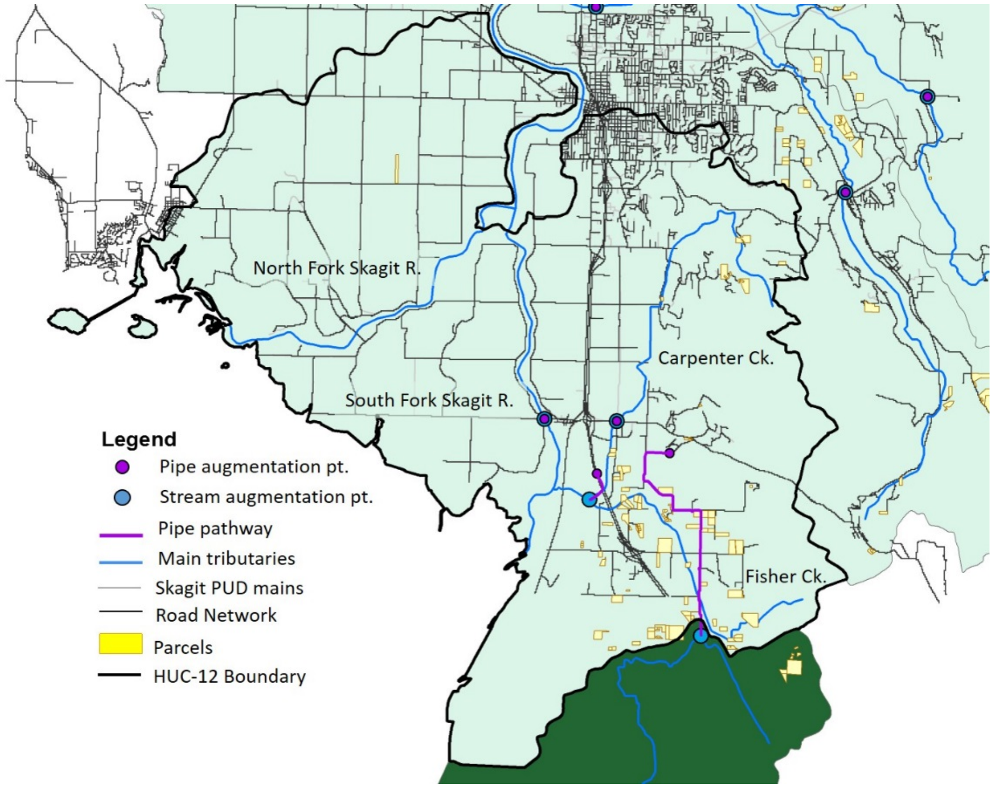

Figure 8. Least Cost Approach results in the Skagit Delta-Frontal Skagit Bay (171100070204)

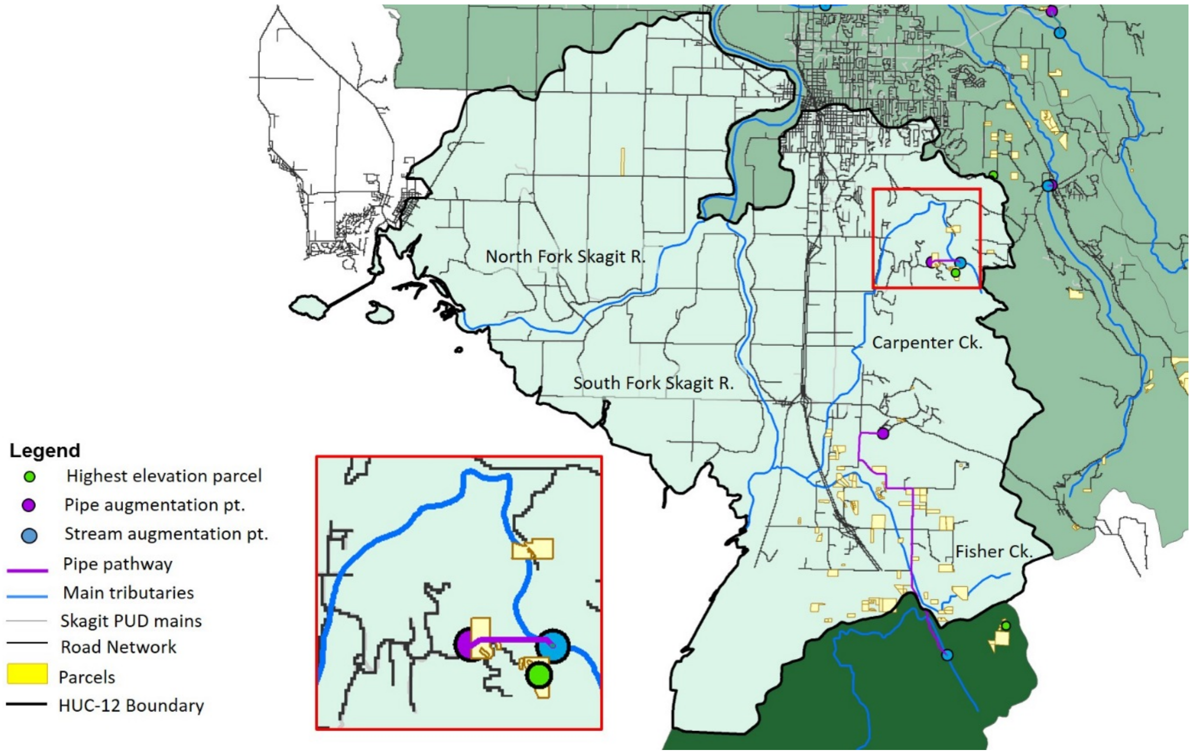

Figure 9. Highest Elevation Approach results in the Skagit Delta-Frontal Skagit Bay (171100070204). Inset focuses on augmentation point on Carpenter Creek.

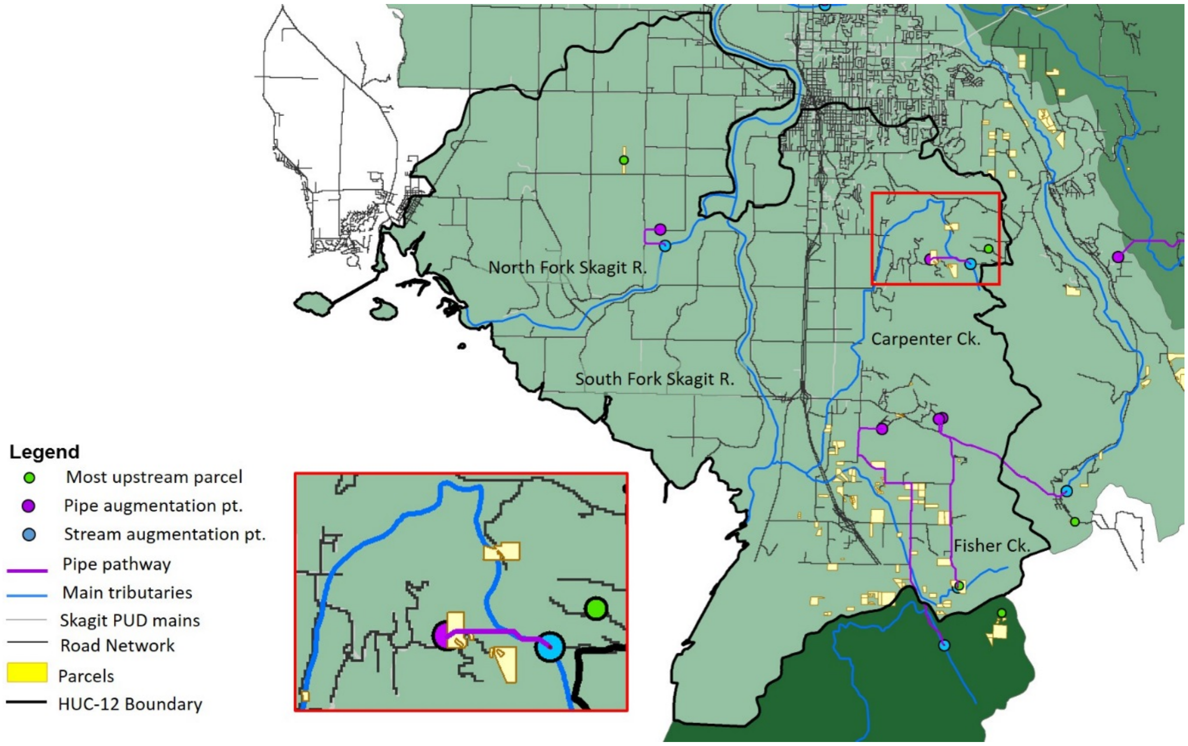

Figure 10. Most Upstream Approach results in the Skagit Delta-Frontal Skagit Bay (171100070204). Inset focuses on augmentation point on Carpenter Creek.

5 Trucking for Mitigation by Flow Augmentation or Aquifer Recharge

The focus of this study in terms of trucking is to provide water for mitigation through either flow augmentation or aquifer recharge in contrast to trucking potable water to each house for direct consumption. The primary difference in the cost estimates for these two approaches is due to the quantity of water being moved. Trucking water for mitigation requires moving about $1/10^{th}$ as much water compared to direct use in the case of indoor use only. This does mean that the transportation modeling done for this analysis can be directly used to estimate costs for trucking water for direct use if needed. Similar to the piping scenario, it is useful to have a method for developing an upper and lower cost estimate. In the results below we assume that water is being trucked to a location that is the same distance as the most distant property in each subbasin. The analysis was also done assuming less costly mitigation points including the average distance for all properties in a subbasin. Due to space we do not report those results here.

Another way in which we made a choice to try and not underestimate trucking cost estimates was to focus on one of two approaches for calculating costs. The two approaches are the Truck Operating Cost Approach and the Commercial Truck Rate Approach. The truck operating cost approach uses the Truck Cost Model (Figure 11), developed by Mark Berwick (2003) at the Upper Great Plains Institute at North Dakota State University and included the inputs below for vehicle operating and fixed costs. The payload of 33,377 lbs. assumes a 4,000-gallon truck capacity, tandem axle, straight truck which is common in the region[1]. Larger capacity tractor trailer trucks would have difficulty navigating tight turn spaces. Given that the shipment of water by truck requires specialized truck equipment, the market for contracting commercial firms to provide this service in the Skagit Valley region is quite thin. Transportation firms providing these services were contacted in order to obtain reasonable rates. This is the basis for the Commercial Truck Rate Approach. The rates were all comparable and between $115 and $120 per hour for delivery, utilizing a 4,000-gallon water truck. This approach merely took this quoted rate, included ½ hour of loading and unloading time and the round-trip travel time from Mt. Vernon to each household. In reporting results we focus on the Commercial Truck Rate Approach because they are higher in almost all cases.

Additional costs for the trucking scenario include a cistern located at the augmentation point which is assumed to require ¼ acre of land. The total cost for these two items together was assumed to be $12,000. In contrast to the piping scenario, the per unit cost for water was assumed to correspond to a wholesale price. Based on values from Seattle Public Utilities, non-peak wholesale price for 2015 is close to $1.50 per 100 cubic feet, or $0.002/gallon. The reason for using a wholesale price is that trucking water from a central location does not require the allocation of resources and potentially forgone opportunity to supply water to an expanded public water system that is relevant for the piping scenario.

Inputs

Variable Costs	
Weight	
Pay Load	33,377
Tractor Weight (Pounds)	17,500
Trailer Weight (Pounds)	1,000
Fuel Cost	
Fuel Price/Gallon	$2.750
Loaded Truck Miles/Gallon	5.50
Empty Truck Miles/Gallon	6.50
Percent Time Loaded	50%
Percent Time Empty	50%
Round Trip Travel Distance (Miles)	80.00
Labor Cost	
Round Trip Driving Time (Hours)	2.50
Unloading Time (Hours)	0.50
Loading Time (Hours)	0.50
Dwell Time (Hours)	0.50
Driver Labor Cost/Hour	20.00
Tire Cost	
Tractor Tire Cost/Tire	$400
Trailer Tire Cost/Tire	$300
Tractor Tire Miles/Tire	250,000
Trailer Tire Miles/Tire	50,000
Maintenance and Repair Cost	
Base Repair Cost/Mile	$0.0900

Fixed Costs	
Equipment Cost	
Purchase Price of Tractor	$95,000
Purchase Price of Trailer	$15,000
Useful Life of Tractor (Years)	5
Useful Life of Trailer (Years)	5
Interest Rate	8%
License Fee	
Annual License Fee	$1,718
Number of Tractors and Trailers in Fleet	4
Annual Miles	80,000
Management and Overhead Cost	
Overhead Cost Rate	4%
Insurance Cost	
Insurance Premium	$9,000

Run Model

Outputs

Total Trucking Cost	**$165.75**
Total Trucking Cost/Hour	$41.44
Total Trucking Cost/Mile	**$2.0719**
Total Trucking Cost/Ton	$9.9320
Total Trucking Cost/Loaded Ton-Mile	**$0.2483**

Figure 11. Inputs into Truck Operating Cost Model shown in a screen capture from the software (variable costs are the same as reoccurring costs).

[1] Based upon phone conversations with several trucking firms in the area.

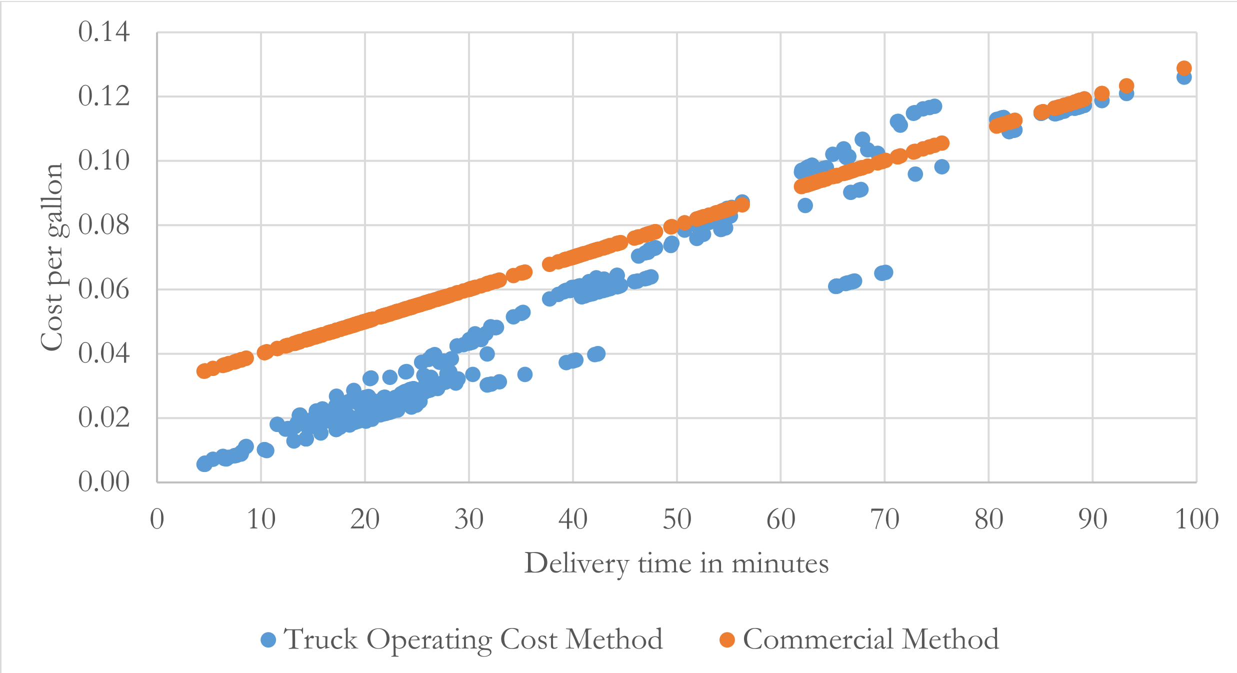

Figure 12. Comparison of cost per gallon for each of the affected properties.

5.1 Results

Results are shown in Table 6. Indoor use costs per household range from $6,190 to $21,002. Indoor plus outdoor costs per household range from $184,597 to $196,469. Key findings are as follows. First, it is clear that trucking for outdoor use is not worth considering because it is always more expensive than piping (see Tables 4 and 5). Second, there are a number of subbasins where cost per household for indoor-only mitigation is in the $6,000 to $8,000 range, which makes trucking cheaper for most properties relative to piping for indoor use (See Tables 3, 4, and 5). Third, the reason that closer in subbasins could be more expensive than those further out is that there are fewer properties by which to divide the fixed costs of the augmentation point infrastructure.

Table 6. Summary of results for trucking for flow augmentation scenario.

Ref #	HUC 12 Name	Parcels	Wholesale price ($/ga)	Trucking cost ($/ga)	Annual cost per household indoor	Annual cost per household indoor/outdoor	Fixed costs per subbasin	Indoor only	Indoor/outdoor
10	Lower Samish River	7	0.002	0.057	366	1,938	12,000	8,045	186,184
7	Joe Leary Slough-Frontal Padilla Bay	17	0.002	0.0537	346	1,830	12,000	6,682	185,175
2	Copper Creek-Skagit River	9	0.002	0.1048	663	3,508	12,000	12,793	185,803
8	Lake Shannon-Baker River	1	0.002	0.0819	521	2,756	12,000	21,002	196,469
14	Rocky Creek-Skagit River	7	0.002	0.1114	704	3,725	12,000	13,882	186,184
1	Aldon Creek-Skagit River	39	0.002	0.0993	629	3,328	12,000	11,177	184,777
13	Prairie Creek-Sauk River	23	0.002	0.1288	812	4,297	12,000	14,556	184,991
15	Sauk River	6	0.002	0.1055	667	3,531	12,000	13,534	186,469
5	Grandy Creek	28	0.002	0.0746	475	2,516	12,000	8,648	184,898
11	Mill Creek-Skagit River	52	0.002	0.1001	634	3,354	12,000	11,186	184,700
9	Loretta Creek-Skagit River	28	0.002	0.0729	465	2,460	12,000	8,465	184,898
3	Day Creek	3	0.002	0.0701	447	2,368	12,000	11,736	188,469
6	Hansen Creek	79	0.002	0.0703	449	2,375	12,000	7,909	184,621
4	East Fork Nookachamps Creek	17	0.002	0.0533	343	1,817	12,000	6,639	185,175
12	Nookachamps Creek	33	0.002	0.0549	353	1,869	12,000	6,469	184,833
17	Skagit River	1	0.002	0.0367	240	1,271	12,000	16,152	196,469
16	Skagit Delta-Frontal Skagit Bay	94	0.002	0.0545	351	1,856	12,000	6,190	184,597
18	Stillaguamish River-Frontal Port Susan	7	0.002	0.0563	362	1,915	12,000	7,970	186,184

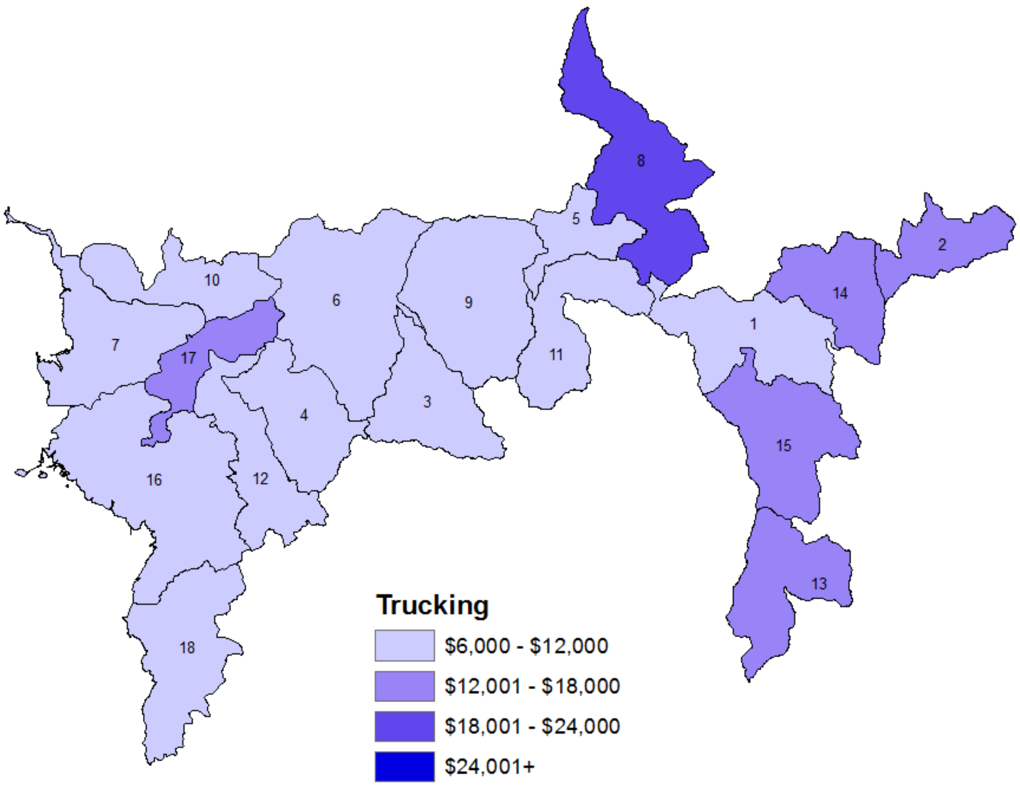

Figure 13. Total cost per household in present value terms for trucking for mitigation assuming a discount rate of 5%, a 30-year time horizon, and 18 gallons per day (0.02 ac-ft/year).

6 Winter Flow Capture and Rainwater Collection as Alternatives

Winter flow capture has already been considered in the Carpenter-Fisher, as discussed earlier in this document. The consideration that shapes the winter flow capture scenario in this report is a landowner in Child's basin that is interested in building a pond for storage to be used for mitigation for nearby properties. There was a consideration of doing a basin scale analysis that would involve a search for locations ideal for capturing winter flows. This alternative was decided against because it was determined that the results were very unlikely to focus in on alternatives that had a good chance of succeeding. The key limitation is not potential sites that would be amenable to pond construction, but rather landowners willing to build a pond. Therefore, our approach has been to use the Child's basin case study to consider whether this alternative may be the lowest cost option for some locations.

The EPA provides guidance on detention ponds in Report EPA 832-F-99-048. It goes without saying that costs depend on a number of factors related to the soil type, terrain, and climate. The EPA estimates typical costs to range between $23.46 to $48.30 per cubic meter[2]. Child's basin contains fewer than 10 properties. For ease of calculation we simply assume that it is necessary to mitigate for 10 properties. Assuming indoor and outdoor use, this corresponds to 1 acre-foot of storage. There are 1,233 cubic meters in an acre-foot, so the lowest cost estimate is $28,926, or $2,892 per house. Using the upper cost estimate from EPA gives $5,955 per household. Due to evaporative loss and other inefficiencies it is not advisable to assume the smallest possible pond size. A more conservative estimate is to assume pond capacity that is double the mitigation requirement. Taking the average of the two EPA values gives $8,848 per household.

In comparison to the other scenarios a cost of $8,848 per household is higher than most of the trucking and piping flow augmentation results. However, it is in the realm of being cheaper for some of the subbasins that are more expensive for both of these options. Therefore, it could make sense for the more remote properties.

Rainwater catchment has been considered in detail by Ecology and other entities (Dept. of Ecology, draft; Ecosystem Economics, 2015). Therefore, we do not revisit any of those cost calculations. Our focus here is to compare those costs to the piping, trucking, and winter flow capture estimates. As summarized in the report "Skagit Basin Water Supply Options" (Ecology, draft), capital costs for rainwater collection are estimated to be $25,000 per house. It is more expensive than trucking for indoor use only for all subbasins. The only option for which it is cheaper in all subbasins is trucking for indoor and outdoor use. It varies by subbasin as to whether it is cheaper or more expensive than piping for indoor only or indoor and outdoor use.

7 Integrated Results

In this section we integrate the results from all of the alternatives to provide a more direct comparison across all of the subbasins. The most important thing to consider when comparing piping and trucking is the relative difference of fixed versus recurrent costs. The fixed costs for the infrastructure at the augmentation point are likely to be very similar between the two options. This means that when looking at the difference in costs between the two scenarios the trucking costs are essentially all variable costs. Piping becomes more competitive than trucking if the piping distance is short and the quantity of water is large, all other things equal. This can be seen by comparing the results across the subbasins where these two factors vary. The point can be made clearer with a graphical display of cost per household as piping distance or water quantity vary, which is summarized below after compare trucking and piping directly across subbasins.

Table 7 compares cost estimates by subbasin for piping and trucking where the upper cost estimates within each scenario is applied. Trucking is the cheaper option for 396 properties compared to 59 for piping. This table is also useful for considering whether winter flow storage and rainwater collection may be cheaper options. To summarize, mitigation costs are estimated to be between $6,000 and $10,000 for most of the 455 affected properties. The subbasins where costs are

[2] The report was written in 1999 so it is necessary to inflate these values to current dollars. $1 in 1999 is worth approximately $1.38 in 2016 dollars (Bureau of Labor Statistics).

higher than $10,000 contain very few properties. A summary of the number of properties by mitigation cost range is reported in Figure 14.

Table 7. Summary of results comparing trucking and piping mitigation assuming indoor use only.

Ref #	HUC 12 Name	Parcels	Trucking	Piping indoor	Cheaper option	Cost for cheapest
10	Lower Samish River	7	8,045	10,702	Trucking	8,045
7	Joe Leary Slough-Frontal Padilla Bay	17	6,682	10,996	Trucking	6,682
2	Copper Creek-Skagit River	9	12,793	21,055	Trucking	12,793
8	Lake Shannon-Baker River	1	21,002	88,803	Trucking	21,002
14	Rocky Creek-Skagit River	7	13,882	9,364	Piping	9,364
1	Aldon Creek-Skagit River	39	11,177	11,635	Trucking	11,177
13	Prairie Creek-Sauk River	23	14,556	53,881	Trucking	14,556
15	Sauk River	6	13,534	51,948	Trucking	13,534
5	Grandy Creek	28	8,648	15,291	Trucking	8,648
11	Mill Creek-Skagit River	52	11,186	7,600	Piping	7,600
9	Loretta Creek-Skagit River	28	8,465	17,833	Trucking	8,465
3	Day Creek	3	11,736	118,493	Trucking	11,736
6	Hansen Creek	79	7,909	13,579	Trucking	7,909
4	East Fork Nookachamps Creek	17	6,639	14,463	Trucking	6,639
12	Nookachamps Creek	33	6,469	12,211	Trucking	6,469
17	Skagit River	1	16,152	23,959	Trucking	16,152
16	Skagit Delta-Frontal Skagit Bay	94	6,190	8,367	Trucking	6,190
18	Stillaguamish River-Frontal Port Susan	7	7,970	48,045	Trucking	7,970
Totals	Properties	451				
	Piping Cheaper	59				
	Trucking Cheaper	392				

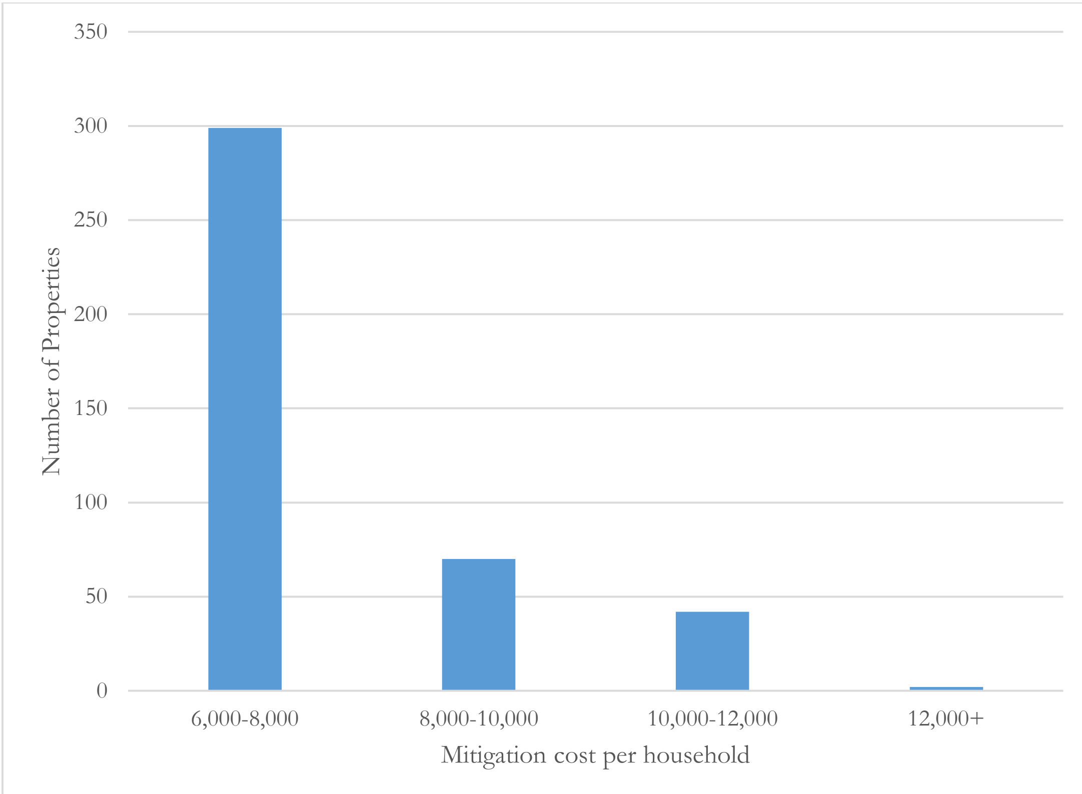

Figure 14. Number of properties by mitigation cost range.

7.1 Effect of Piping Distance and Number of Properties on Relative Costs

It is possible to get a sense of how piping distance and the quantity of water affect the relative cost of the piping option compared to trucking as a function of the variation in (1) piping distance and (2) the number of houses in each subbasin. However, given the critical importance of these two factors it is useful to describe a hypothetical subbasin to identify where there are crossing points where piping goes from being less to more expensive than trucking. We can also assume some fixed amount of piping and consider how the number of houses affects the cost of piping relative to trucking. If there are only a few houses in the subbasin then trucking is likely to be cheaper unless the piping distance is very short. However, as the number of houses increases trucking will become more expensive than piping at some point.

In order to display these relationships on 2-dimensional plots we can only consider the effect of either piping distance or number of houses at one time. Results for piping distance assuming a fixed number of houses is shown first, and then we proceed to vary the number of houses while keeping the piping distance fixed.

7.1.1 Varying Piping Distance

Consider a subbasin that has 50 houses. Also, assume that the reoccurring cost to each household each year is $473 following from Section 4.4, which corresponds to a one-time present value cost of $7,271/house. For a trucking cost we use $0.1/gal because it is close to the average across all houses in the basin as shown in Figure 12. This corresponds to a reoccurring cost of $652/house per year, or $10,023/house in present value terms.

The results in Figure 15 show that piping is the cheaper option if the pipeline is less than about three-quarters of a mile. The effect of higher variable costs for trucking are made abundantly clear by considering mitigation that also permits outdoor use. Results for this same hypothetical subbasin are shown in Figure 16. Even at 3 miles of pipeline the piping option is cheaper than the trucking option because 5 times as much water is needed per house.

7.1.2 Varying the Number of Homes

Now we consider how the number of houses affects the relative cost of piping and trucking in a hypothetical subbasin where there is a fixed amount of pipeline that cost $100,000 in total to put in place. This scenario is most valuable for considering whether future development could switch a basin from being one where trucking is the cheaper option to one where piping is. We assume that the piping distance is 0.5 miles, and that only indoor use is permitted.

Figure 17 shows that 36 houses is the crossing point. Any more than that and piping is the cheaper option. The curvilinear shape of the piping cost curve is characteristic of a situation where there are both fixed and variable costs. As these options are considered in more detailed subbasin specific analyses, projections of future development could be overlaid with what was done in this section to help determine the best approach.

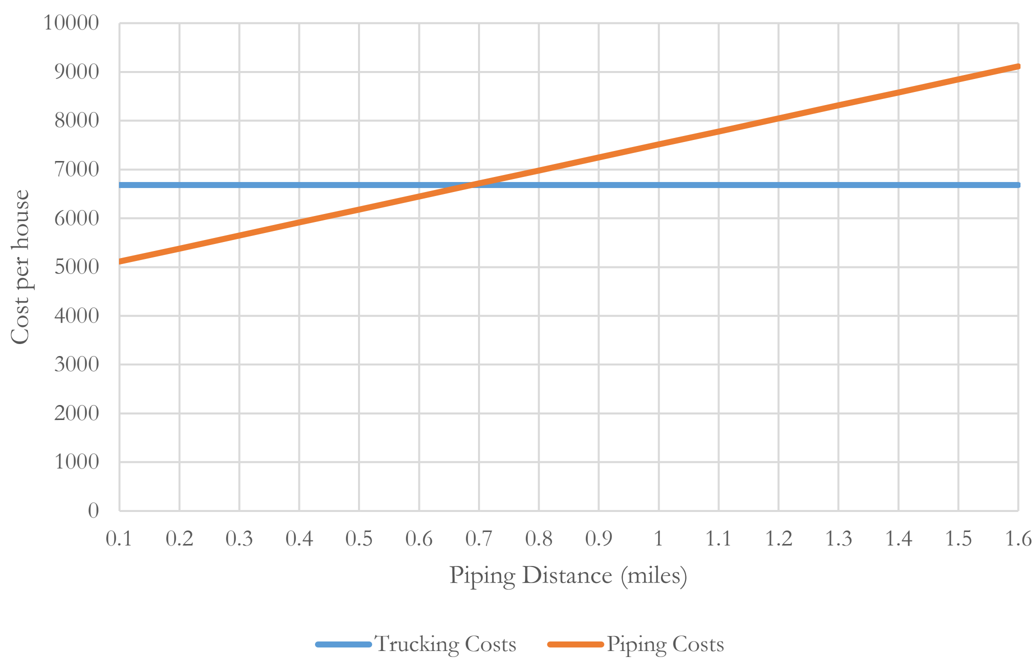

Figure 15. Effect of piping distance on the relative cost of piping versus trucking for a hypothetical subbasin with 50 houses that have <u>indoor use only</u> with a trucking distance of 1 hour.

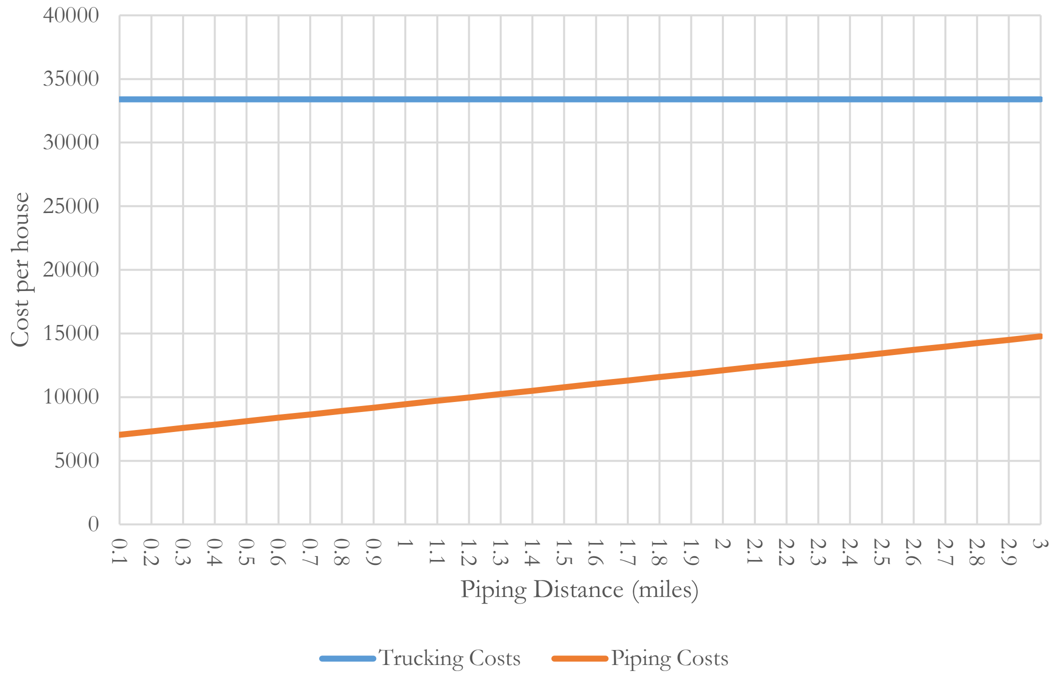

Figure 16. Effect of piping distance on the relative cost of piping versus trucking for a hypothetical subbasin with 50 houses that have indoor and outdoor use only with a trucking distance of 1 hour.

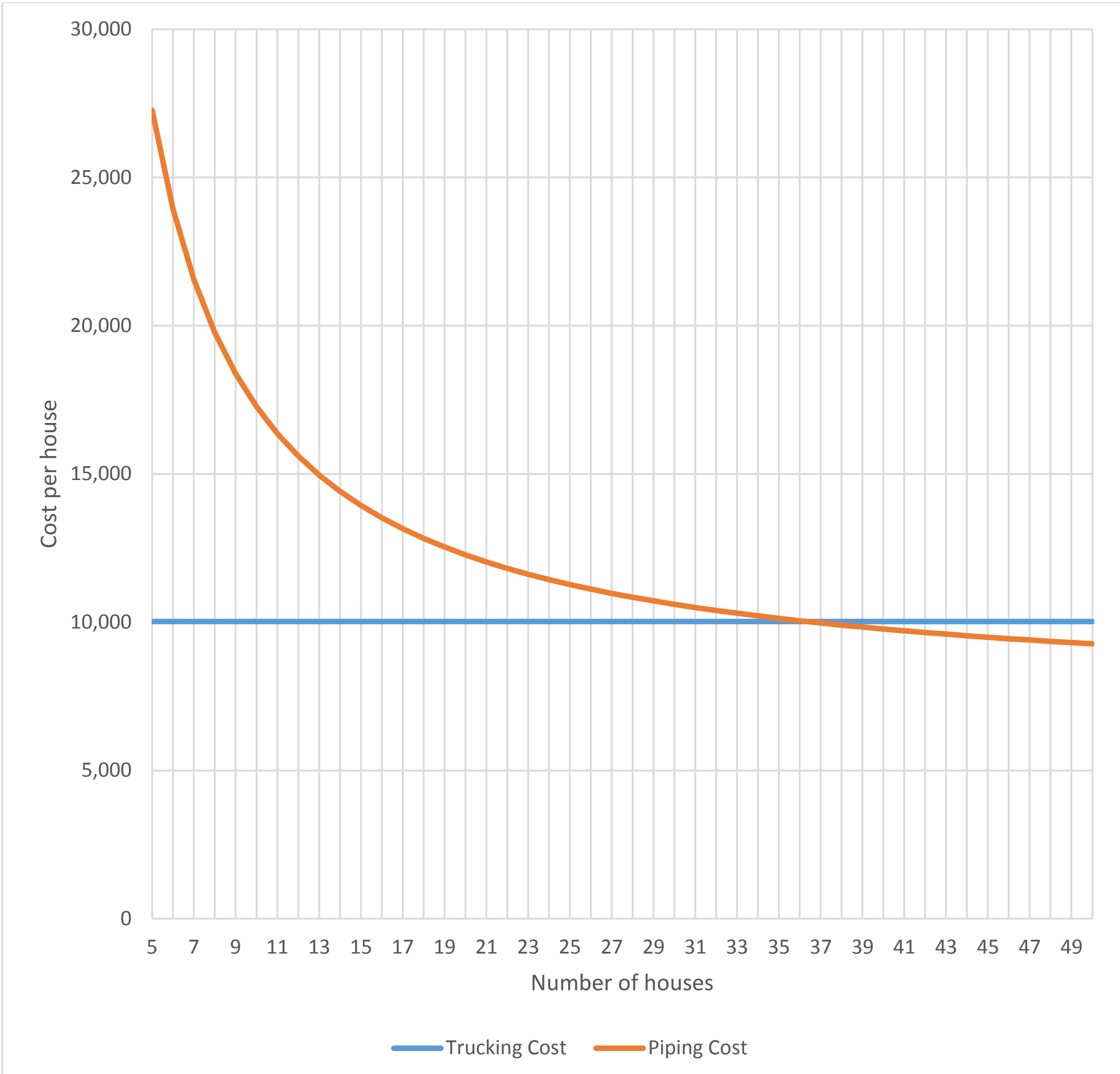

Figure 17. Effect of the number of houses on relative costs of piping versus trucking assuming indoor use only, a trucking distance of 1 hour, and a pipeline distance of 0.5 miles.

7.2 Augmentation Points and Biological Concerns

One of the points demonstrated in Section 7.1 is that piping distance is an important determinant of whether trucking or piping is cheaper. Throughout the analysis an important assumption was made that there is only one augmentation point per subbasin. This could be problematic if there are critical low flow issues on multiple sub-tributaries and sub-sub-tributaries to the Skagit River within the same subbasin, which could require multiple augmentation points. This has important implications for the relative cost of trucking versus piping. In short, multiple augmentation points increases piping costs relative to trucking costs. Both scenarios would require the same augmentation point infrastructure investments. There is no increase in fixed costs for trucking relative to piping. Multiple augmentation points would require additional pipelines.

To consider how likely this potential is we reviewed the Washington Department of Fish and Wildlife Fish Atlas. We filtered the data to include documented, presumed, and modeled presence of fish in order to be as inclusive as possible. Fall Chinook and Summer Steelhead are present in all of the tributaries considered for augmentation in this study with only a few exceptions (upper reaches of Day Creek, Grandy Creek, East Fork Nookachamps, Colony Creek, Carpenter Creek, Fisher Creek, Stillaguamish River, and Joe Learly Slough). To make a first pass at identifying subbasins that may require multiple augmentation points we identified six that were highest priority. They include Skagit Delta-Frontal Skagit Bay, Nookachamps Creek, Stillaguamish River-Frontal Port Susan, Joe Learly Slough-Frontal Padilla Bay, Oyster Creek-Frontal Samish Bay, and the Lower Samish River. Three additional subbasins that warrant additional investigation are East Fork Nookachamps, Hansen Creek, and Loretta Creek-Skagit River.

7.3 Inchoate Rights

Another limitation to the piping scenario is if satellite systems of Skagit PUD do not in fact have adequate inchoate rights. This could either be a situation where they are up to their limit with current use, or where no additional use would be feasible given expected future development within the direct service area of the system. Information on inchoate rights for the satellite systems of Skagit PUD are reported in the Skagit PUD Water System Plan (2013), which can be found online at http://www.skagitpud.org/resources/document-repository/water-system-plan-2013/ . Inadequate inchoate rights would simply rule out the piping scenario for the relevant subbasin unless another satellite system was in close proximity.

8 Conclusions

This report develops cost estimates and comparisons for instream flow augmentation or aquifer recharge by pipe and by truck for mitigation so that existing houses built after 2001 can use their wells. In summary, trucking for flow augmentation is cheaper than piping for most subbasins for indoor use only applications, but piping is in all cases cheaper than trucking for combined indoor and outdoor use. Most (about 370 of 451 households) can be provided mitigation water for between 6 and 10 thousand dollars in net present value terms. With this as the main finding of the study, we highlight our perspective on the additional advantages and disadvantages of trucking versus piping.

Piping Advantages

1. Makes outdoor use financially feasible.
2. Conditional on the satellite system having adequate inchoate rights, piping makes future development more feasible in that piping costs per house decrease with the number of houses in contrast to the trucking option.

Piping Disadvantages

1. Becomes much less financially feasible if multiple augmentation points are required in each subbasin.
2. Requires a significant new scope of work for Skagit PUD. This could entail additional staff which is not a cost considered in this report.

Trucking Advantages

1. Trucking is the cheapest option for most subbasins based on modeling done in this study.
2. Does not require an institutional change where public water systems are tasked to do something they have not had to in the past.
3. Trucking costs could decrease relative to what was assumed in this study if this option is implemented in practice and new entrants come in to offer water hauling services.

Trucking Disadvantages

1. Additional truck hauling activity on roads may be a disamenity to local residents if additional truck traffic on roads will be a nuisance. It seems unlikely given the number of truck trips required but it is considering as it has been discussed multiple times in outreach meetings.
2. Does not become cheaper with future development on a $/house basis.
3. Would likely only support indoor use due to its high cost for outdoor use.

Trucking is the cheaper option in many subbasins when considering indoor use only. However, trucking is almost certainly financially infeasible for outdoor water use. From a strict financial return perspective, if homebuyers value outdoor use more than the mitigation cost then it may be worth pursuing the piping option. When comparing indoor only versus indoor/outdoor use cost estimates it is the case that adding outdoor use significantly lowers the cost per unit of water to the household for piping, but not for trucking, leading to the large escalation of outdoor use costs for trucking. It is likely that most households value indoor use water significantly more than outdoor use. For piping, the value for outdoor use only needs to be greater than the variable costs of pumping the water in order for households to be better off with a higher mitigation cost that allows for indoor/outdoor use. This is an important difference between piping and trucking that should be considered when evaluating which alternative to pursue.

Two subbasins are particularly well-suited for considering mitigating via piping for both indoor and outdoor use due to relatively lower costs and for reaching a large number of homes: Mill Creek (ref# 11) and Skagit Delta-Frontal Skagit Bay (ref# 16). Mill Creek contains 52 homes, and the Skagit Delta subbasin, containing Fisher and Carpenter basins, contains 94 homes. The estimated costs per household are $10,687 and $11,742, respectively. If piping implementation is pursued incrementally, these subbasins are reasonable targets for early implementation. If this approach is taken, it would be useful to carefully collect data on the implementation process.

Given the different characteristics of piping and trucking for mitigation, it may also be worth considering sequential implementation of trucking and piping, which could be referred to as a Truck Now/Pipe Later approach. There are three reasons to consider this option.

1. Piping is more expensive for most currently affected households,
2. There is no trucking specific infrastructure required that is also not required for piping,
3. Piping will tend to be more cost-effective with future development (to a point),
4. Future development is uncertain.

The investments required at the point of augmentation for trucking can be used in the piping scenario, but piping requires more fixed, up-front investment than trucking (laying pipes). The fact that no additional trucking-specific infrastructure investment is required means that a sequential approach with trucking implementation first postpones the risk of making a sizeable up-front investment in piping until more is learned about demand for outdoor use for current homes, and until more is learned about demand for future development. The Truck Now/Pipe Later approach simultaneously allows for relatively inexpensive indoor mitigation to be provided to most homes while providing the option to expand with piping when and where there is a clear demand for it.

9 References[3]

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[3] For data source references, see Table 1.

10 Appendix 1. GIS Routines for Finding Piping Paths

10.1 Least Cost Approach

<u>Analysis methods</u>:

1. Find shortest distance between municipal pipe infrastructure polylines and mainstem polylines in each basin (Generate Near Table tool- ensure "Location" option is checked).

2. Use the table created to make new shapefiles of the mainstem augmentation points (Display XY Data – From X and From Y) and infrastructure pipe points (Display XY Data tool- Near X and Near Y) There should be one each per basin.

3. Break each new shapefile into individual point shapefiles. This can be done manually using the Select tool, or can be automated in ArcGIS Modelbuilder using the Iterate Feature Selection and Select tools.

4. Create a batch process that runs the least cost path model (Section 1.2.4) to find the augmentation pathway with the smallest elevation change for each stream-pipe pair in a basin.

5. Convert least cost path raster files created in Step 4 to polylines (Raster to Polyline tool).

6. Add a new column to each polyline file and assign the corresponding mainstem Flow_ID (for identification purposes).

7. Append all polyline files, create a new field named "Dist_m", and calculate line length (in meters) for each pipe pathway (Calculate Geometry tool).

8. Final pathways shows routes from existing mains to augmentation points. *Note: because the polyline conversion is from the center of a raster cell, the actual lines may not directly intersect with the pipe and mainstem points used.*

10.2 Highest Elevation Approach

<u>Analysis methods</u>:

1. Link elevation point data to each parcel (Extract Values to Points tool- ensure Append Input Raster Attributes is checked).

2. Identify and select the property in each HUC-12 basin with the maximum elevation (Attribute Table > Summarize by HUC-12 and Maximum elevation).

3. From the table created, select the corresponding properties from the parcel shapefile and export to a new shapefile containing only those selected properties at maximum elevation (Select tool). There should be 1 per basin.

4. Find shortest distance between properties with the greatest elevation and mainstem polylines for each basin (Generate Near Table tool- ensure "Location" option is checked).

5. From the table created, make a new shapefile of the nearest stream points (Display XY Data tool- Near X and Near Y). There should be one each per basin.

6. Find shortest distance between the nearest stream points (Step 5) and the existing utility infrastructure polylines for each basin (Generate Near Table tool- ensure "Location" option is checked).

7. From the table created, make a new shapefile of the nearest pipe points (Display XY Data tool- Near X and Near Y).

8. Break the new shapefiles created in Steps 5 and 7 into individual point shapefiles. This can be done manually using the Select tool, or can be automated in ArcGIS Modelbuilder using the Iterate Feature Selection and Select tools.

9. Create a batch process that runs the least cost path model (Section 1.2.4) to find the augmentation pathway with the smallest elevation change for each stream-pipe pair in a basin.

10. Convert least cost path raster files created in Step 9 to polylines (Raster to Polyline tool).

11. Add a new column to each polyline file and assign the corresponding mainstem Flow_ID (for identification purposes).

12. Append all polyline files, create a new field named "Dist_m", and calculate line length (in meters) for each pipe pathway (Calculate Geometry tool).

13. Final pathways show routes from existing mains to augmentation points. *Note: because the polyline conversion is from the center of a raster cell, the actual lines may not directly intersect with the pipe and mainstem points used.*

10.3 Most Upstream Approach

Overview of approach: This approach represents an alternate high-end estimate of piped mitigation costs. Here, augmentation occurs on a mainstem at the point closest to the most upstream property in the HUC-12 basin (one property per basin).

Analysis methods:

1. Create points on the mainstem flowline (Feature Vertices to Point tool).

2. Select the lower most point on each mainstem flowline (basin discharge point) and create a new point shapefile (Select tool).

3. Find furthest parcel property from discharge point (Generate Near Table tool- ensure "Location" option is checked, "Find Nearest Feature" is unchecked). This is the "most upstream" parcel for each basin.

4. Using the table created, select the matching properties from the parcel shapefile and export to a new shapefile containing only those selected properties (Select tool). There should be 1 per basin. *Note: before exporting selected properties, visually verify results (e.g. properties are in the same HUC-12 basin as the discharge point, properties visually match expectations of "most upstream")*

5. Find shortest distance between the most upstream properties and mainstem polylines for each basin (Generate Near Table tool- ensure "Location" option is checked).

6. From the table created, make a new shapefile of the nearest stream points (Display XY Data tool- Near X and Near Y). There should be one each per basin.

7. Find shortest distance between the nearest stream points (Step 6) and the existing utility infrastructure polylines for each basin (Generate Near Table tool- ensure "Location" option is checked).

8. From the table created, make a new shapefile of the nearest pipe points (Display XY Data tool- Near X and Near Y).

9. Break the new shapefiles created in Steps 6 and 8 into individual point shapefiles. This can be done manually using the Select tool, or can be automated in ArcGIS Modelbuilder using the Iterate Feature Selection and Select tools.

10. Create a batch process that runs the least cost path model (Section 1.2.4) to find the augmentation pathway with the smallest elevation change for each stream-pipe pair in a basin.

11. Convert least cost path raster files created in Step 10 to polylines (Raster to Polyline tool).

12. Add a new column to each polyline file and assign the corresponding mainstem Flow_ID (for identification purposes).

13. Append all polyline files, create a new field named "Dist_m", and calculate line length (in meters) for each pipe pathway (Calculate Geometry tool).

14. Final pathways show routes from existing mains to augmentation points. *Note: because the polyline conversion is from the center of a raster cell, the actual lines may not directly intersect with the pipe and mainstem points used.*