SEATTLE PUBLIC UTILITIES

Landsburg -
DRAFT Fluoridation and Chlorination Alternatives Study

(Stage Gate 2)

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EXECUTIVE SUMMARY

Chlorination (using chlorine gas) has been practiced at Landsburg since the 1950s. It was originally used for drinking water treatment, but since a treatment plant upgrade in 2004, it is used for pipeline maintenance and prevention of aquatic nuisance species from entering Lake Youngs.

Fluoridation (using fluosilicic acid) has been practiced at Landsburg shortly after a public vote for fluoridation was approved by voters in 1968. It provides a public health benefit in terms of preventing tooth decay.

This study describes the background of the fluoridation and chlorination systems and discusses the regulatory, risk and other drivers affecting the systems. This study also evaluates alternatives for future fluoridation and chlorination system improvements. This study also evaluates the supporting systems for chlorination, most notably the aging elevated water tank serving the chlorine gas feed system.

The chlorination system has two main drivers for evaluating potential changes: regulatory and safety considerations. The system met current building and fire codes when it was constructed and modified through the years, but it does not meet current codes, being "grandfathered." The current regulatory environment makes it difficult for this older system to stay in compliance, especially in regards to potential safety issues associated with an uncontrolled release of chlorine gas into the surrounding environment.

The fluoridation system has one main driver for evaluating potential changes: since 2008, the typical algae bloom in Lake Youngs changed in character, becoming filamentous and stringy. The stringiness of the algae caused several treatment plant shutdowns due to in-plant clogging, and has necessitated about $250,000 in treatment plant upgrades to address algae clogging. The algae also passed through the treatment plant, affecting water customers by clogging water meters and control valves. A 2009 Lake Youngs Expert Review Panel noted that the fluoridation of water entering Lake Youngs resulted in a relatively significant phosphorus load to the lake, increasing the potential for phosphorus-driven algae blooms. The Panel recommended moving the point of fluoride addition to downstream of Lake Youngs, reducing the phosphorus load to Lake Youngs by about 20 percent.

Recommendations for the fluoridation and chlorination systems as well as the elevated water tank include:

- **Moving fluoride is a policy decision.** It would cost about three million dollars to design and construct a new fluoride system at Lake Youngs, and would also require up to $100,000 in additional annual costs compared to what is already being borne by the staff at Landsburg. At this point, it is not possible to quantify enough financial benefit associated with moving the fluoride addition point to Lake Youngs enough to offset the additional costs. Also, recent success at bypassing Lake Youngs during algae blooms (thus avoiding 100 percent of the algae bloom during lake bypass periods) will continue to decrease the impact of these algae blooms on the water distribution system.

- **Replace the chlorine gas chlorination system with a liquid sodium hypochlorite (12 percent bleach) system.** This change will significantly reduce the regulatory requirements associated with chlorine gas use, and will eliminate the safety risks associated with exposure to chlorine gas.
- The elevated water tank, which provides chlorine injector water as well as on-site non-potable water needs, will not be needed once the chlorine gas system is replaced with a sodium hypochlorite system. The elevated water tank can be left as is, to be employed as an occasional backup water supply, or can be decommissioned. Potable water will need to be identified for the building (there is no current potable water system) in addition to confirming that the existing vertical turbine pumps can continue to be used for fire fighting needs, but without a water storage tank.

1. ANALYSIS OF CHLORINATION SYSTEM

This study presents background information on chlorination at Landsburg, previously practiced for water treatment purposes and now practiced for pipe maintenance and water quality purposes.

BACKGROUND

Purpose of Chlorination at Landsburg

Landsburg uses chlorine gas for chlorination. Until 2004, chlorination at Landsburg was considered a drinking water treatment function. In 2004, when the new Cedar Water Treatment Facility (TF) at Lake Youngs went on-line, the point of treatment compliance was moved to the Cedar TF.

Chlorination is now practiced at Landsburg for purposes other than water treatment. The decision to continue chlorinating at Landsburg was based on a 2005 study conducted by SPU Water Quality Lab staff. Primary drivers for continuing chlorination at Landsburg included:

1. Prevention of significant biofilm accumulation between Landsburg and Lake Youngs. Before chlorination at Landsburg, there had been significant biofilm accumulation, including growth of periwinkles (encased Caddis fly larvae), causing increased pipe maintenance and decreased flow associated with reduced pipe diameter.

Non-chlorinated section of pipe at Landsburg; periwinkle growth after one year

2. Prevention of exotic aquatic species from entering Lake Youngs. For example, Eurasian milfoil was accidentally introduced into Lake Youngs (by boat) in the early 1990's and SPU has spent over $500,000 eradicating this exotic aquatic macrophyte. Effects of invasive species may be particularly significant to the Cedar system (compared to other large water supply systems) due to the fact that the treatment plant does not include filtration.

3. Minimizing changes in raw water quality delivered to the new Cedar TF. For example, eliminating chlorination at Landsburg could increase disinfection by-product formation through the Cedar TF and increase ozone demand.

An internal meeting of SPU water quality staff (Dave Hilmoe, Bill Wells, Alex Chen, Jim Nilson, Moya Joubert, Liz Johnson, Lynn Kirby) was held in January 2010. At that meeting, it was confirmed that continuous chlorination at Landsburg should continue indefinitely.

The decision to continue chlorinating at Landsburg was vetted through this project's Economist and Asset Management Reviewer. The potential risks of stopping chlorination at Landsburg include letting invasive species into Lake Youngs, which could 1) cost significant amounts to remove from the lake (such as milfoil) and 2) potentially drive SPU towards the construction of a filtration process in addition to the current water treatment facilities at the Cedar TF. The cost for filtration has been estimated at approximately $200M, based on 2002 consultant's estimates and comparison to recent cost estimates developed for similarly-sized filtration facilities by Tacoma and Portland.

The potentially large risk cost and the poor ability to predict the probability of aquatic invasive species in Lake Youngs associated with stopping chlorination and the effects of such species on the water treatment facilities and Lake Youngs, resulted in a decision to halt any further economic analysis associated with stopping chlorination at Landsburg.

Chlorine Use and Cost

Historical chlorine doses at Landsburg vary considerably throughout the year, based on the turbidity in the water being diverted. Current turbidity-based targets and action levels are on average about 0.5 mg/L lower than before the 2005 Landsburg study. Current guidelines are as follows:

Table 1-1. Turbidity-Based Action Levels for Landsburg Diversion

If Turbidity (NTU) is:	Set Target Chlorine Residual at:
0.20 – 0.49	0.45 mg/L
0.50 – 0.99	0.50 mg/L
1.00 – 1.19	0.60 mg/L
1.20 - 1.49	0.70 mg/L
1.50 – 1.69	0.80 mg/L
1.70 – 1.99	1.0 mg/L
2.00 – 4.99	1.2 mg/L
5.00 +	Diversion Closed (If turbidity limits are raised above 5 NTU, then the chlorine target should be set to 1.4 mg/L)
Begin Turbidity Shutdown At	**If Diversion Flow Is**
3.5 NTU	< 80 MGD
3.0 NTU	80 – 120 MGD
2.5 NTU	>120 MGD

Since the Cedar TF went on-line in 2004, Landsburg has spent approximately $50,000 per year for chlorine gas. Actual expenditures have varied based on year-to-year changes in water demand, specified chlorine dose, and unit cost of chlorine gas.

Labor costs specifically associated with the chlorination system at Landsburg are not available. Almost all of Landsburg's staff time is all charged to SPU's "Chlorination O&M" budget activity number (with the rest going to the "fluoridation" and "regulatory compliance" charge codes), but much of the staff time is actually spent operating the Landsburg diversion dam. Therefore, reporting the labor costs for chlorination based on the historical budget records would be extremely conservative.

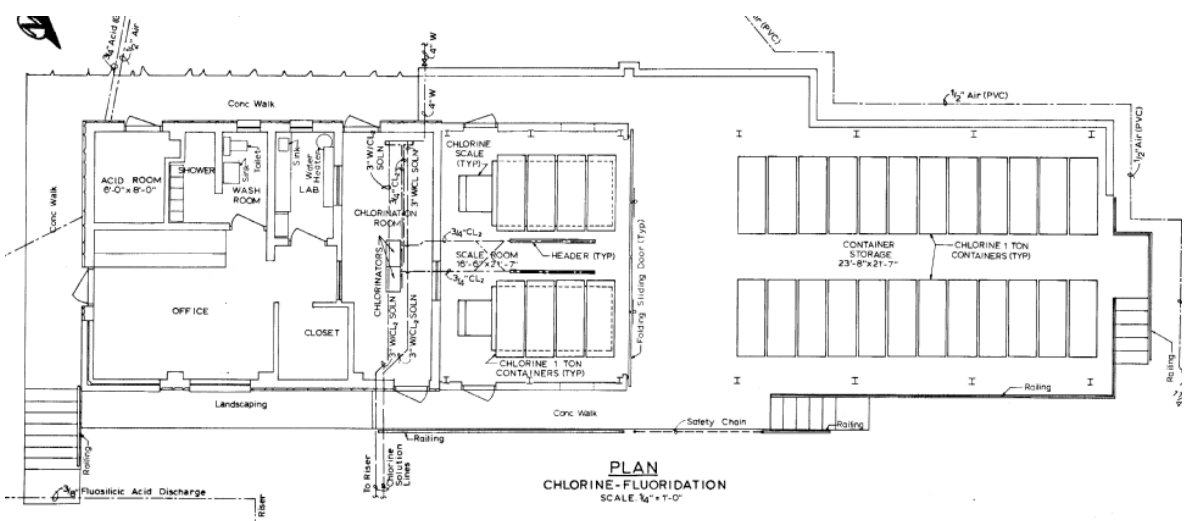
Chlorination System

The chlorination system consists of a storage area, chlorine gas vacuum withdrawal system from two banks of 4-1 ton chlorine containers, chlorinators, injectors, and a chlorine residual analyzer.

Operators load, unload, and store full and empty 1-ton chlorine containers on the loading dock. There is room to store 12 full 1-ton containers and 12 empty 1-ton containers.

In the tank room, 2 banks of 4-1 ton containers can be brought on line to provide a maximum chlorination rate of 3,500 lbs/day. The chlorinator room houses the chlorine residual analyzer, chlorine injectors, and 2-2,000 lbs/day chlorinators. The practical capacity of each chlorinator is actually closer to about 1,750 lbs/day due to freeze prevention considerations in the chlorine cylinders and feed lines.

Chlorine residual is monitored continuously on a strip chart with audible alarms in the event chlorine residual goes outside preset limits. Operators must manually adjust chlorine feed rates. The facilities remain essentially unchanged since the facility was built in the 1950's, other than addition of a loading dock, hoist, injector room, and tank room in the mid-1980's.



Chlorine Storage and Feed Rooms in Treatment Building

Left Photo: Chlorine Gas Storage; Right Photo: Chlorine Gas Feed

Chlorinators

The chlorination system is adequately sized. The practical limit on chlorine withdrawal is 1,750 lbs/day per chlorinator, or 3,500 lbs/day for both chlorinators. The peak daily chlorine requirement in the last few years has been approximately 3,200 lbs/day, and that maximum requirement is not anticipated to increase.

REGULATORY REQUIREMENTS

Five major regulatory requirements affect the Landsburg chlorination facilities: the Emergency Planning and Community Right-to-Know Act, the Worker and Community Right-to-Know Act, the Uniform Fire Code, the Process Safety Management rule, and the Risk Management Plan rule. Each is described below.

1. Emergency Planning and Community Right-to-Know Act

The Emergency Planning and Community Right-to-Know Act is an EPA rule designed to allow state and local planning for chemical emergencies, to provide for notification of emergency releases of chemicals, and to address communities' right-to-know about toxic and hazardous chemicals. Complying with this rule entails regular reporting to local and state emergency response entities about storage and release of certain hazardous chemicals, including chlorine gas.

SPU is in compliance with its Emergency Planning and Community Right-to-Know Act requirements at Landsburg.

2. Worker and Community Right-to-Know Act

The Worker and Community Right-to-Know Act is Washington state's law designed to help workers understand and mitigate the potential dangers of chemicals that they work with, including chlorine gas.

SPU is in compliance with its Worker and Community Right-to-Know Act requirements at Landsburg.

3. Uniform Fire Code

Since 1988, the Uniform Fire Code (UFC) regulations have required some form of treatment or containment for gas chlorination systems using and/or storing above 150 pounds of chlorine at a given time. Options for addressing the requirements include chlorine scrubbers and cylinder containment vessels.

Landsburg does not have scrubbing or containment equipment; however, chlorination systems that were in operation prior to the adoption of the requirement in 1988 are not subject to it until major modifications are made to the system. If significant changes are needed for the chlorination system in the future, the system will have to be upgraded to meet the current UFC regulations.

4. Process Safety Management

In 1992, the Occupational Safety and Health Administration (OSHA) put forth the requirements of its Process Safety Management (PSM) rule (29 CFR 1910.119). SPU must comply with this regulation, given the threshold quantities (TQs) of chlorine stored on site. The TQs are 1,500 pounds for chlorine. The rule contains the compliance requirements for thirteen PSM plan elements that apply to the Landsburg facilities. These elements are:

- Employee participation; Process safety information; Process hazard analysis; Operating procedures; Training; Contractors; Pre-startup review; Mechanical integrity; Hot work permits; Management of change; Incident investigation; Emergency planning and response; and Compliance audits

Compliance with the rule requires the development of written policies, procedures, and records for each of these plan elements.

SPU is in compliance with its PSM requirements at Landsburg.

5. Risk Management Plan

SPU is required by the EPA to produce a Risk Management Plan (RMP) under 40 CFR 68. Like the OSHA PSM rule, this requirement is based on the quantity of regulated substances stored on-site. However, the threshold quantities are different: 2,500 pounds for chlorine (compared to 1,500 pounds for the PSM threshold). RMPs were required to be submitted to EPA by June 21, 1999 and updated every five years thereafter.

The requirement elements of an RMP include a hazard assessment, prevention program, and emergency response plan. The hazard assessment is an evaluation of the offsite effects of an accidental release. The prevention program addresses all those measures that must be taken to prevent an accidental release. The level of detail for the prevention program depends on the program level of the process. A process can be classified as program 1, 2, or 3, with program 3 having the most stringent requirements. Because the Landsburg is in Washington State, which is an OSHA "state-plan" state, the chlorine process is classified as program 3. However, a program 3 prevention program is virtually identical to an OSHA PSM plan and so the two plans can be easily developed and incorporated together.

SPU is in compliance with its RMP requirements at Landsburg. Landsburg keeps a combined RMP/PSM compliance document in the office in the Treatment Building. The next update of the RMP is due in 2014.

LONG-TERM ALTERNATIVES FOR CHLORINATION

Keeping an eye towards long-term strategy, this study evaluated five alternatives for continued chlorination at Landsburg:

1. Maintaining the current chlorination system as is;
2. Keeping the current chlorination system and adding a chlorine gas scrubber;
3. Changing to a liquid sodium hypochlorite system (using bulk/concentrated hypochlorite delivery);
4. Changing to a liquid sodium hypochlorite system (using on-site generation of hypochlorite); and
5. Changing to a tablet-based hypochlorite feed system.

1. Maintain Gas Chlorination System As Is

This alternative assumes no capital upgrades to the chlorination system. At a future date, one of the other alternatives would need to be pursued if any significant improvements are made to the system, per the requirements of the UFC.

2. Keep Gas Chlorination System – Add Scrubber

This alternative assumes that the current gas chlorination system is left in place, but a scrubber is added to bring the system in compliance with the treatment requirements of the UFC.

The UFC states that treatment systems are required for chlorine gas systems that store or use more than 810 cubic feet (approximately 150 pounds) of gas. Treatment systems "shall be capable of diluting, adsorbing, absorbing, containing, neutralizing, burning or otherwise processing the entire contents of the largest single tank or cylinder of gas stored or used (Article 80, Section 3.3.1.3.5.2)." The most widely used treatment systems are scrubbers. In the event of a gas leak, one style of scrubber takes the gases and neutralizes them via mixing with a neutralizing agent such as caustic soda. The components of this type of scrubber system include a caustic soda tank and feed system, a fan, controls and instrumentation, and various piping and ducting. The caustic soda is fed into the ejector via a recirculation pump and mixes with the incoming gas to be neutralized. Liquid droplets interact with and absorb the gas. Crossflow packed bed sections are used to maximize the contact between gas and caustic soda. A clean gas outlet is provided for gas discharge.

Other scrubbers operate on a simpler concept: a fan draws the chlorine gas through a several-foot deep bed of adsorbent media. These newer systems are more expensive to purchase than caustic soda scrubbers but require less maintenance. Caustic soda systems require periodic testing and change-out of the stored caustic soda, as well as maintenance on the chemical piping and pumps; caustic soda tends to crystallize in piping and pumps. Maintenance on an adsorbent-type scrubber is limited to maintenance of the fan and media change-out after major chlorine leaks.

Other means of complying with the UFC include containment vessels and emergency valve shut-off systems. Containment vessels provide individual secondary containment for each container in the event of a leak. Emergency valve shut-off systems use a control panel to shut off on-line chlorine feed valves if a chlorine leak is detected.

In this application, a scrubber is recommended. Containment vessels can be a viable and cost-effective alternative; however, the providing a containment vessel for each ton container would be significantly less cost-effective than installing a single scrubber serving the entire system. Emergency valve shut-off systems would not address the possibility of a leak in the off-line (stored) containers.

The capacity of the scrubber is required to equal that of the largest single storage vessel – in this case, one ton. Caustic soda would be the neutralizing agent, since it is capable of treating both chlorine and sulfur dioxide. Alternatively, a dry adsorbent media-type scrubber could also be considered. Either way, a 3,000 cfm (minimum air capacity) scrubber would be required to neutralize a one-ton cylinder. Modifications to the existing chlorination building would be required so that in the event of a leak, all ventilation to the atmosphere would be shut down, and all gases would be routed to the scrubber. The modifications would include enclosing the covered (but open to the environment) storage area, along with HVAC system improvements to both the storage and feed rooms.

The scrubber can be located outdoors, but an enclosure to provide protection from the elements is often recommended by manufacturers. For reference, the Tolt TF scrubber is outdoors, while the Cedar TF scrubber is in a roofed structure without enclosed walls. Heat tracing of tanks and piping may also be recommended, depending on the configuration selected. The entire system should be tied into the emergency generator system in the event of a combined power outage and gas leak.

3. Liquid Hypochlorite Disinfection – Bulk (Concentrated) Sodium Hypochlorite

Due to the requirements of RMPs and the high cost of treatment or containment vessels, many utilities have been switching to liquid hypochlorite. Hypochlorite does not have the same potential for catastrophic release as gas chlorination. Hypochlorite systems also do not have the treatment/containment, OSHA, and RMP requirements that are associated with gas chlorination.

Many cities and utilities, including SPU (throughout its distribution system) and the Cities of Everett and Tacoma, have replaced their chlorine gas systems with liquid sodium hypochlorite systems at several of their facilities. Liquid sodium hypochlorite solution is available at a concentration of approximately 12 percent by weight. A 12 percent solution has an equivalent chlorine content of 1 pound of chlorine per gallon of solution. Liquid sodium hypochlorite will result in a slight increase in the pH of the finished water.

The primary benefit of sodium hypochlorite is that it is a safer system than chlorine gas since there is no possibility of a catastrophic release that could harm operators or nearby residents. This option can be reliable, when backup storage and pumping capabilities are included.

One main drawback to liquid hypochlorite is high cost (a per-equivalent-pound-of-chlorine cost of approximately three times that of chlorine gas) and its tendency to degrade, which is affected by product concentration, temperature, and exposure to sunlight. Degradation decreases the amount of effective hypochlorite disinfection in the liquid and increases the formation of byproducts such as chlorate ion (ClO_3^-). Additional monitoring of the stored product is recommended for such systems. Dilution of the delivered product will reduce the rate of degradation. The bulk product is often diluted and stored at a concentration of 6 to 8 percent if it will be stored for more than 30 days.

Another significant drawback to using liquid hypochlorite is the increased level of operations and maintenance attention required. Sodium hypochlorite is a corrosive liquid that requires additional operator handling precautions and frequent maintenance of the feed equipment. In particular, sodium hypochlorite tends to off-gas, caused by the formation of mostly oxygen during degradation. The off-gassing can result in vapor lock of the pumps and piping system and must be vented properly. Therefore, it is important that venting of these gases be provided immediately before the pumps and that the metering pumps and system be designed to handle the off-gassing. Also, sodium hypochlorite at these concentrations is a corrosive liquid; it is important that suitable materials, such as Viton, are specified for pump seals and o-rings. Nevertheless, leaks at pipe joints and fittings should be anticipated, requiring additional maintenance. Since hypochlorite at these concentrations is considered a hazardous material, double-contained storage and piping is required. Double containment of storage can be accomplished via low concrete walls around storage tanks, or by using double-contained tanks (a tank within a tank).

Sodium hypochlorite also requires more truck deliveries; a typical truck delivery of chlorine gas carries as much equivalent chlorine as about six 4,000 gallon tanker trucks of sodium hypochlorite at 12 percent concentration. Therefore, sodium hypochlorite-related truck traffic would be six times as much as chlorine gas-related truck traffic.

Positive displacement diaphragm pumps are commonly used for metering sodium hypochlorite. Other pumps, such as peristaltic pumps, can also be used (and are now standard equipment for SPU's distribution system hypochlorite feed facilities).

For this alternative, the system would consist of three 8,000 gallon outdoor storage tanks. At a peak week usage of approximately 2,000 to 2,500 pounds per day, the tanks would allow about 10 days of storage at 12 percent concentration, or the solution could be diluted and stored at 8 percent with about seven days of storage. The outdoor storage of the tanks is to save capital and O&M (building heating) cost and minimize hypochlorite venting-related corrosion in enclosed buildings. The storage tanks would require a UV-resistant coating for this purpose, as well as some heat tracing for freeze protection of piping.

It should be noted that if the point of fluoride addition is moved to Lake Youngs, then the fluoride tank pad and secondary containment can be re-purposed for sodium hypochlorite. New storage tanks would be needed, but the concrete pad and secondary containment system could stay as is. New feed pumps would be required, but they could be located in the existing fluoride feed pump room.

4. Liquid Hypochlorite Disinfection – On-Site Hypochlorite Generation

On-site hypochlorite generation produces a dilute (0.8 to 1 percent) hypochlorite solution. The process uses water, salt, and electricity to produce the hypochlorite solution. Each pound equivalent of chlorine requires approximately 3.5 pounds of salt, 15 gallons of water, and 2.5 kilowatt-hours (kWh) of electricity. On a per-pound of equivalent chlorine basis, on-site generation is approximately in-between the cost of chlorine gas and the cost of delivered 12 percent hypochlorite.

As with 12 percent sodium hypochlorite, on-site generation is considerably safer than chlorine gas. Advantages over 12 percent sodium hypochlorite is that there is no concern for product degradation due to lower concentration and shorter holding times, and operators only handle dry salt and 0.8 percent sodium hypochlorite, rather than 8-12 percent liquid hypochlorite.

An on-site generation system consists of a brine tank/salt saturator, a rectifier, PLC, generating units, and a product tank. Metering pumps for the brine and hypochlorite are also required. The brine solution can be held for long periods of time, and with the lower feed concentration, there is no concern with chlorine degradation at lower feed rates. High quality vacuum-dried salt is delivered in 50 pound bags, or can be delivered by truckload and blown into specialized salt saturator tanks. The water used for preparing the brine is typically softened to prevent scaling in the system, requiring disposal of brine waste from the softener to the sanitary system. Disposal of brine waste could be a significant consideration for Landsburg, where the waste would likely have to go to the on-site septic system, or be trucked off-site if not allowed to go to the septic system.

The product hypochlorite solution is transferred to a storage tank from which it is metered to the system. The sodium hypochlorite storage tank provides a minimum of one day reserve of the feed product as well as a place to vent hydrogen gas, a by-product of the hypochlorite generation process, to the atmosphere.

The one day storage tank sizing requirement stems from manufacturers providing 24-hour service guarantees. In the event of a short-term outage or routine maintenance of the generating unit, the product tank is sized sufficiently to continue operations for up to one day while the manufacturer's service representative can address any issues. If a longer shutdown of the generating unit is anticipated, 12 percent sodium hypochlorite can be delivered to and fed from the product tank.

One significant consideration is the maintenance required for this type of system. It is much more mechanically complex than either a chlorine gas or a bulk liquid sodium hypochlorite system. Operators must perform regular maintenance on all the critical parts, including brine pumps, product pumps, flow meters, electrolytic cells (which are only under warranty for seven years), and instrumentation such as level controllers.

For this alternative, the equipment required would include a large salt saturator for receiving tanker shipments of salt; a 2,500 lbs/day on-site generation system; and product tanks to hold a total of at least 40,000 gallons (one day's worth of 0.8 percent hypochlorite).

5. Liquid Hypochlorite Disinfection – Tablet Feed of Hypochlorite

Calcium hypochlorite tablet feed systems are simple and reliable and have been used for many different small systems, including chlorination at municipal pump stations. Historically, they have been used where the applied feed rate is constant and thus do not require extensive automation or controls. However, some systems have been installed that allow for flow-paced and compound loop controls.

These systems use 3-inch diameter tablets that come in 100 pound containers. Calcium hypochlorite tablets contain approximately 65 percent available chlorine by weight. When kept dry, calcium hypochlorite has a much lower rate of degradation compared to concentrated liquid sodium hypochlorite.

The package tablet feeder consists of a storage vessel for loading the tablets. The units are rated by the maximum weight of tablets that can be loaded (i.e. a 500 pound unit can hold 500 pounds of tablets which equates to 325 pounds of available chlorine). The chlorine dose is controlled using a split flow, with some flow going to the calcium hypochlorite feeder while the rest of the flow bypasses the tablet feeder. The flow to the feeder comes in contact with the bottom layer of the stored tablets and slowly dissolves them. Metering pumps are used to deliver the hypochlorite solution to the point of application.

The main drawback of tablet feed systems has been the cost of calcium hypochlorite tablets, which is significantly higher than the cost of chlorine gas and bulk liquid hypochlorite (approximately 5-7 times more expensive than chlorine gas and 3-4 times more expensive than bulk sodium hypochlorite, on a per-equivalent-pound-of-chlorine basis). For comparison purposes, it will be shown in the next section that the cost of hypochlorite tablets makes this alternative prohibitively expensive.

ANALYSIS OF ELEVATED WATER TANK

Currently, the elevated water tank behind the Treatment Building serves pressurized water to the chlorine injectors. It also serves pressurized water to the fire hydrant and to the emergency eyewashes and showers.

If kept in place, the elevated water tank is aging, does not meet current seismic codes, and should be repainted. This section examines alternatives to address the chlorination system's water supply needs, if the chlorination system is kept: either bringing the elevated water tank up to current seismic codes and repainting it, or removing the elevated water tank and replacing it with a smaller, ground-level hydropneumatic tank.

The water storage tank is a 50,000 gallon, painted steel, elevated storage tank. It is located immediately behind the chlorination building. The tank was constructed in the early 1930's; shop drawings (by Pittsburgh-Des Moines Steel Co.) are dated May 10, 1930.

Elevated Water Tank (left photo shows the Treatment Building in the foreground)

Water for the tank is supplied by ground-level vertical turbine pumps that draw suction from the Landsburg diversion, downstream of the vee-screen installed as part of the 2003 Fish Passage Project. The two pumps are located inside a building enclosure and are each rated at 300 gpm at 150 ft of head.

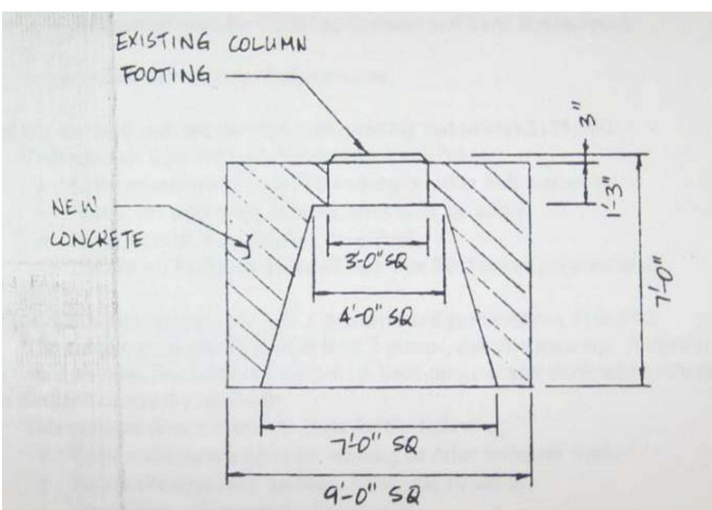
The water from the elevated water tank is used for water supply for chlorine gas injectors and also serves pressurized water to the fire hydrant and to the emergency eyewashes and showers. It also serves as a backup supply for nonpotable uses inside the building such as laboratory water and water for flushing the toilet (there is no potable water supply to the building; potable water must be brought from off-site). In addition to basic pressure requirements for building service water, the elevated water tank provides the required pressure of about 65-plus psi for the chlorine injectors.

Pumps feeding Elevated Water Tank (one of two pumps shown)

Seismic Analysis

As part of a utility-wide seismic evaluation performed in the early 1990s, Cygna Group found that the elevated tank would stand up to a Class II earthquake (72-year exceedance), with "moderate soil overstress resulting in lower effective loads in the structure." However, the tank would not remain operable after a Class I earthquake (475-year exceedance); the significant issue was uplift of the column footings resulting in a loss of lateral load capacity, combined with the "moderate problem" of yielding of the braces.

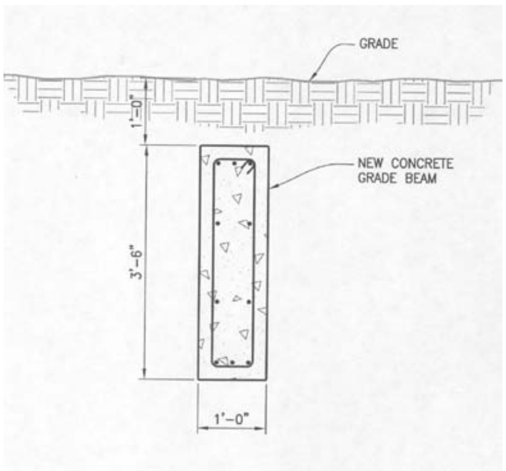
The recommended seismic upgrade in the Cygna Group study was to increase the hold-down capacity of the footings by placing new concrete over the existing footings. Brace replacement was not recommended, because brace yielding during a Class I earthquake would not compromise the safety of the tank.



1990 Cygna seismic upgrade recommendation – add concrete to existing column footings

The Cygna Group's analysis was based on seismic codes as of 1990. The primary standard applying to steel tanks today is the most recent version of American Water Works Association (AWWA) D100(-05), Standard for Welded Steel Tanks for Water Storage.

Before a comprehensive analysis of tank performance under current codes was completed, it was thought that different upgrades would also be needed, compared to those recommended in the 1990 Cygna Group report. Instead of placing new concrete over the existing footings, grade beams (connecting the existing footings) were contemplated. Partial or total brace replacement was also considered (discussed later in this study).



Section through New Grade Beams Connecting Existing Footings (dimensions shown are only rough estimates)

Recently, Tank Industry Consultants (TIC) completed a seismic analysis of the elevated tank based on current AWWA standards. TIC's analysis showed that in a significant seismic event:

1. Replacement of the diagonal bracing rods and tank struts (the horizontal members connecting the columns) was recommended given the severe level of overstress (2 to 6 times the stress levels permitted) on the diagonal braces; the struts would need to be replaced to accommodate the additional load from the new braces.

2. The columns are moderately overstressed (approximately 30 percent); the column foundations are moderately overstressed (approximately 20 percent); and the anchor bolts are adequately sized but poorly detailed. These items are a much lower priority than replacing the diagonal braces and horizontal struts.

It should be noted that TIC's analysis is conservative, rigorously following the most recent AWWA standards in terms of compliance or non-compliance. In contrast, a more recent trend in seismic engineering is "performance-based analysis," in which the analysis balances cost of upgrades versus performance during various magnitudes of seismic events. This "performance-based analysis" approach is more in-line with what SPU has done in terms of elevated tank seismic upgrades over the last 15 or so years.

Structural / Coating Analysis

The elevated tank was most recently inspected, by Martin Jacobsen of SPU, in 1996 and again in 2003, and then in 2007 by TIC. Generally, the inspection found that the tank shell was in good shape.

The exterior paint had a red lead primer applied in 1957. In 1983, the tank's exterior was blasted to SSPC-SP6 and coated with a zinc yellow-iron oxide primer with green silicone alkyd top coats. It is likely that 95-100 percent of the red lead primer was removed. The latest report indicated that the exterior paint was chalky and faded, but the prime coat was not exposed anywhere. There was considerable corrosion on 20 percent of the heads of the bolts that hold the roof to the tank. Some miscellaneous safety (ladder/railing) improvements were also recommended.

It should be noted that lead has been detected in the soil around the base of the tank, most likely from the previous exterior re-coating work.

The interior was lined with coal tar enamel in 1957. During the latest inspection, the interior lining was noted to be in fair shape; the coal tar is beginning to crack, but no rust was showing at the cracks. A new interior ladder was recommended due to corrosion of the existing ladder.

Typically, steel water tanks should be on a 10 to 20 year cycle for repainting. A well maintained tank with periodic painting and inspection should be expected to have a service life on the order of 50-100 years. Without properly maintained paint protection, the tank shell can corrode at a rate of up to 10 mils per year.

LONG-TERM ALTERNATIVES FOR ELEVATED WATER TANK

Again keeping an eye towards long-term strategy, this study evaluated several alternatives for water storage at Landsburg. Maintaining the status quo was not an acceptable due to the seismic deficiencies in the tank.

1. Keeping the elevated tank along with a seismic retrofit and repainting the interior and exterior;
2. Replacing the elevated tank with a new elevated tank or standpipe;

3a. Replacing the elevated tank with a ground-level hydropneumatic tank, including demolition of the elevated tank;

3b. Replacing the elevated tank with a ground-level hydropneumatic tank, including draining the elevated tank and leaving it in place without other modifications;

4. If the chlorine gas system is replaced with a bulk sodium hypochlorite system, the elevated water tank would not be needed. The only treatment-related water needs for sodium hypochlorite are for low pressure water for dilution of sodium hypochlorite; that function could be provided by the existing river pumps without any storage. All other chlorine-related alternatives need continuous pressurized water supply, so this alternative would not apply.

1. Keep Elevated Tank, with Seismic Upgrades and Repainting

This alternative assumes the elevated tank would stay in place, with interior and exterior repainting, and seismic upgrades to bring it into compliance with current codes.

The interior of the tank should be sandblasted and primed and painted. The TIC study indicates that exterior of the tank appears to be able to be power washed, spot primed, and recoated without having to be sandblasted. If needed, localized spot blasting or grinding can be done on the exterior. If needed, small vacuum systems can be used to capture waste materials associated with localized areas.

Sandblasting the entire exterior would increase the cost, since large-scale measures would be required to capture and dispose of the sandblasted materials.

The primer and paint should be an AWWA, DOH, and NSF-approved coating system. Most recently, zinc-rich urethane primers have been used to prolong the service life of paint systems, because the zinc in the primer tends to act as passive cathodic protection. Most recently, a tank consultant for SPU prepared plans and specifications for re-painting elevated steel tanks; specifications included a three-coat epoxy interior coating system and an exterior coating system consisting of a zinc-rich urethane primer followed by intermediate and top coats of aromatic and aliphatic urethanes, respectively.

Based on previous inspection and construction reports, it is assumed that 95-100 percent of the previous red lead primer was removed during the 1983 exterior re-painting and that minimal or no lead abatement measures are required.

Seismic upgrades include replacement of diagonal bracing and horizontal struts, per the recent Tank Industry Consultants report (as described previously in this report). Lower priority seismic upgrades, such as column/foundation/anchor bolt modifications, were not included in the assumed scope of seismic upgrades.

2. Replace Elevated Tank with a New Elevated Tank (or Standpipe)

This alternative assumes that the elevated tank would be replaced with a similar elevated tank at the same location. Alternatively, a standpipe of equivalent height and usable storage could be provided. A major advantage of this alternative over Alternative 1 is that at 70+ years old, the elevated tank is nearing the normally anticipated end of its life cycle. Of course, replacing a tank instead of upgrading and re-painting it usually entails a significant increase in cost, and the existing tank, if properly maintained, may well have a service life in excess of 100 years.

The advantage of a standpipe over an elevated tank is that a standpipe has more total storage (although the same usable amount) and is much easier to inspect and re-paint due to its more uniform shape. Water quality appurtenances, such as in-standpipe mixing systems, would be required to properly turn over the water in the lower sections of the standpipe (dead storage).

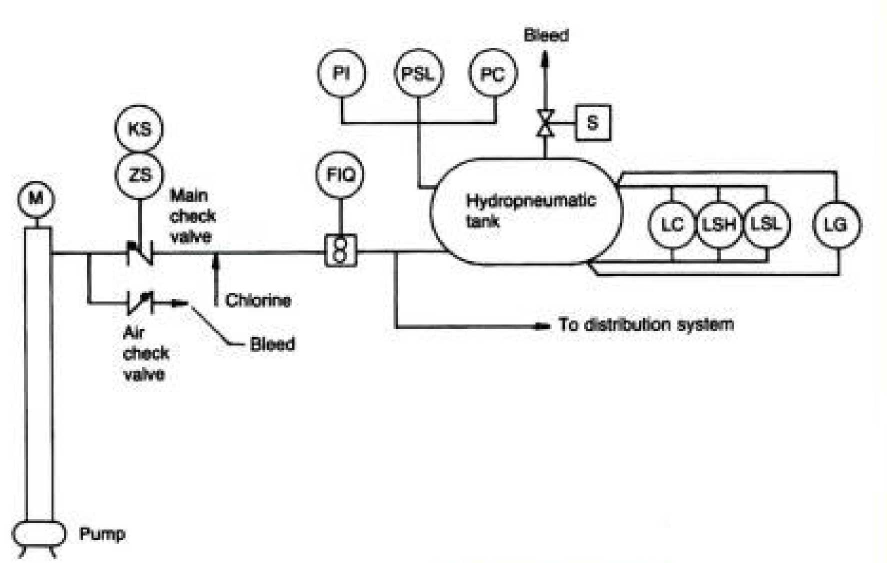
Based on previous projects and quotes from manufacturers, typical unit costs for the two styles of tanks are:

- Elevated tank: between $2.50 and $3.50 per gallon. 50,000 gallons of storage is assumed (to match the existing capacity).
- Standpipe: between $0.55 to $0.75 per gallon. About 200,000 gallons of storage is assumed (to match the existing useful capacity, with the storage from the useful bottom elevation down to the ground level being dead storage)

In addition to the basic unit cost for the two styles of tank, the foundation requirements, the need for in-tank mixing systems, the regular inspection and re-painting cost, and other factors should be considered in a life cycle analysis. For the purposes of this planning study, an elevated tank is assumed, but the overall capital and life cycle cost for both styles of tank are similar.

3a. Replace Elevated Tank with Hydropneumatic Tank, Demolish Elevated Tank

This alternative assumes the elevated tank would be demolished and replaced with a ground-level hydropneumatic tank. Hydropneumatic tanks maintain system pressure by using a reservoir of air in the tank. Typically, hydropneumatic tanks hold much less water than an equivalent elevated tank, so the pumps feeding the hydropneumatic tanks are required to run much more often to make up for the decreased storage volume.



Typical schematic of a ground-level hydropneumatic tank

In previous analyses by SPU staff, no replacement storage was assumed to be needed if the elevated tank were to be demolished. A new pump station was proposed, sized to approximately meet the demands for chlorine injector water. No consideration was made for storage needs, such as during pump failure, or intermittent demands, such as lab use, toilet flushing, or fire flow.

This study assumes that at a minimum, a moderately sized hydropneumatic tank is required. Without a minimal amount of storage, the supply pumps would be required to run continuously to meet chlorine injector water demands. The pumps would also have to meet intermittent water needs such as showers and toilet flushing. This type of operational scenario requires continuous pump operation, resulting in decreased pump life as well as sudden water outages associated with intermittent pump failures. It also requires pumps to operate at several points up and down their operating curve as intermittent demands turn on and off. The significant variation in flow and pressure requirements would range from a maximum of continuous chlorine water supply plus all intermittent demands to a minimum of one or two intermittent demands only, when the chlorine system is turned off during diversion shutdowns.

Preliminary sizing calculations indicate that the tank would need to be at least 1,000 gallons. A larger tank would decrease the demand on the supply pumps. For planning purposes, a 1,500 gallon tank is assumed. A small air compressor is also included for maintenance of the air charge in the hydropneumatic tank. The compressor and overall control system would have to be connected to backup power; the existing backup diesel generator likely has enough capacity to add these loads.

Based on the Washington State Department of Health Water System Design Manual (2001), hydropneumatic tanks are also required to be completely housed, with enough space around the tanks for inspection and maintenance. Therefore, this alternative assumes that a basic structure would be constructed to house the hydropneumatic tank, air compressor and control system.

This alternative also assumes that the elevated tank would demolished. The hydropneumatic tank building could be located where the elevated tank is currently located.

3b. Replace Elevated Tank with Hydropneumatic Tank, Leave Elevated Tank As Is

This alternative is the same as the previous alternative: the elevated tank would be replaced with a ground-level hydropneumatic tank. The difference from the previous alternative is that the elevated tank would stay in place instead of being demolished. The elevated tank would be drained most of the time, which would eliminate the seismic deficiencies, and the tank would be piped and valved for use as a backup to the ground-level hydropneumatic tank. The exterior of the elevated tank would be repainted for basic maintenance purposes. The hydropneumatic tank building could be located adjacent to the elevated tank, but at some point in the future, if the elevated tank were to be demolished, the demolition work would be complicated by the presence of the hydropneumatic tank building if its location is not thought through carefully.

4. No Need for Elevated Tank if Chlorine System Converted to Bulk Sodium Hypochlorite

This alternative is contingent upon the chlorine gas system being converted to bulk sodium hypochlorite. The only treatment-related water needs for sodium hypochlorite are for low pressure water for dilution of sodium hypochlorite; that function could be provided by the existing river pumps without any storage. Thus, the elevated tank could be decommissioned.

This alternative only applies if bulk sodium hypochlorite is used. This is because all other chlorination alternatives require continuous supply of pressurized water.

EVALUATION OF STORAGE TANK ALTERNATIVES

The estimated capital and O&M costs of the water system improvements are summarized in Table 1-1 below. The total present worth and annualized costs are calculated over a 50 year period. The economic assumptions are listed in the appendices, along with the line-by-line cost breakdowns.

Capital costs are based on quotes from vendors and other similar projects. Annual costs are based on quotes from vendors (for power costs) and engineering assumptions about level of operations and maintenance required.

Table 1-1. Storage Tank Alternatives Overall Cost Comparison (50-year Period)

Alternative	Capital Cost	Annual O&M	50-Yr Present Worth O&M	Life Cycle Cost (PW Capital and 50-Yr O&M)
1. Renovate Elevated Tank (Seismic, Re-painting)	$619,000	$3,972	$73,000	$692,000
2. Replace Elevated Tank	$810,000	$4,878	$89,000	$899,000
3a. Hydropneumatic Tank, Demo Elevated Tank	$380,000	$11,686	$213,000	$593,000
3b. Hydropneumatic Tank, Leave Elevated Tank	$323,000	$12,444	$227,000	$550,000
4. No Need for Continuous Pressurized Water (Bulk hypochlorite chlorination alternative only)	$43,000	$1,181	$22,000	$65,000

Based on the cost analysis and qualitative factors, if a continuous supply of pressurized water is needed for the chlorination alternative, then Alternative 3b is recommended because it has the lowest capital and life cycle cost. Although pumped storage is less reliable and more mechanically intensive than elevated gravity storage, the cost analysis shows a significant difference in capital and life cycle cost between elevated and pumped storage. Additionally, leaving the elevated tank piped and valved in place for use as a backup water source (if the hydropneumatic tank experiences mechanical/electrical/control difficulties) will increase the overall reliability of the system.

If the chlorine gas system is converted to bulk sodium hypochlorite, then a continuous supply of pressurized water is not needed, and the elevated tank can be decommissioned (Alternative 4).

EVALUATION OF CHLORINATION (AND STORAGE TANK) ALTERNATIVES

The various chlorination alternatives were combined with the various water system alternatives. The chlorine gas, on-site hypochlorite, and tablet feed hypochlorite alternatives require a continuous supply of pressurized water, so they include the recommended alternative of replacing the elevated tank with a ground-level hydropneumatic tank.

The bulk hypochlorite alternatives only require occasional water supply for washdown and perhaps diluting the hypochlorite down to decrease its loss of strength. Therefore, there is a minimal cost associated with water system improvements for these alternatives.

The estimated capital and O&M costs are summarized in Table 1-2 below. The total present worth and annualized costs are calculated over a 50 year period. The economic assumptions are listed in the appendices, along with the line-by-line cost breakdowns.

Capital costs are based on quotes from vendors and other similar projects. Annual costs are based on quotes from vendors (for chemical and power costs) and engineering assumptions about level of operations and maintenance required. Annual costs also include the cost of regulatory compliance for the chlorine gas alternatives.

A third cost category, Risk Cost, attempts to quantify the safety risks associated with chlorine gas. The risks are examined using a worst-case release scenario of a significant chlorine leak. People in the surrounding area would be severely adversely affected. Risk cost is calculated by multiplying the estimated damage costs by a 10 percent chance of such an event happening in a 100 year period (it should be noted that no such events have ever occurred for the City of Seattle). If a scrubber and building enclosure are added, then the risk is assumed to decrease by a factor of 10.

The Risk Cost also includes a future risk for Alternatives 1 and 2, maintaining use of chlorine gas, in that future regulations may preclude the use of chlorine gas. There are no defined risks other than potential legislation that may require more justification of chlorine gas use, but it is prudent to plan for that possibility given the level of attention associated with municipal use of chlorine gas. The risk was calculated as the capital cost of a hypochlorite alternative times the estimated probability of chlorine gas being precluded, at about 5 percent per year (within the next 20 years).

Another way to calculate Risk Cost is to perform a sensitivity analysis, by which the breakeven point for one alternative over another can be determined. This will be done in the last section.

Alternative 2 also requires modification to the 60-year old building to bring it up to current codes; depending on the local building permit official and fire marshal, the planning-level costs for enclosing the building could be very different from those shown herein.

It should be noted that there is only one vendor for chlorine gas in the Pacific Northwest right now. There were two, but one bought the other’s chlorine delivery business. Should that single vendor decide to stop shipping chlorine gas, then SPU would be faced with an immediate problem (several utilities in the Pacific Northwest would be similarly affected). There are multiple local vendors for all the other types of chlorination strategies.

Additionally, the vendor for chlorine gas delivers the one-ton chlorine cylinders by truck, and there is a risk to society if a traffic accident should occur that releases chlorine gas into the environment surrounding the accident To the author’s knowledge, this has not happened, although there have been a few accidents associated with rail car transport of chlorine gas in larger quantities.

Table 1-2. Overall Cost Comparison (50-year Period)

Alternative	Capital Cost	Annual O&M	50-Yr Present Worth O&M	50-Yr Present Worth Risk Cost	Life Cycle Cost (PW Capital and 50-Yr O&M)
1. Maintain Gas Chlorination System As Is, Add Hydropneumatic Water Tank	$288,000	$80,357	$1,467,000	$7,831,000	$9,586,000
2. Chlorine Gas, Install Scrubber, Add Hydropneumatic Water Tank	$2,233,000	$96,941	$1,770,000	$2,879,000	$6,882,000
3a. Bulk Hypochlorite (12%), assuming new facilities	$2,106,000	$231,495	$4,226,000	$0	$6,332,000
3b. Bulk Hypochlorite (12%), assuming re-use of fluoride facilities if fluoride is moved to Lake Youngs	$594,000	$223,465	$4,080,000	$0	$4,674,000
4. On-Site Hypochlorite Generation, Add Hydropneumatic Water Tank	$5,460,000	$221,832	$4,050,000	$0	$9,510,000
5. Tablet Feed Hypochlorite, Add Hydropneumatic Water Tank	$792,000	$498,416	$9,099,000	$0	$9,891,000

Analysis for Chlorination and Storage Tank

Based on the assumed risk costs, the lowest life-cycle cost alternatives are Alternatives 2, 3a and 3b. Alternative 3's life cycle cost is a little higher than Alternative 3a's, while Alternative 3b's life cycle cost is considerably lower than Alternatives 2 and 3a.

However, no recommendation for chlorination is given yet, due to the potential synergies between chlorination and fluoridation upgrades and sensitivity analysis to be performed for the risk cost analysis. The next section addresses the fluoride issue, and the section after that combines fluoridation and chlorination alternatives and risk costs in order to make a recommendation about the combinations of those alternatives.

2. ANALYSIS OF FLUORIDE SYSTEM

BACKGROUND

Fluoridation at Landsburg

Landsburg has been feeding fluoride into the Cedar side of the SPU water system ever since the public voted for fluoridation in 1968. Fluoridation provides dental health benefits.

The fluoridation system is fairly simple. Fluoride (hydrofluosilicic acid) is stored in 3-8,000 gallon rubber lined tanks. There is sufficient secondary containment storage to store the contents of one tank. A fill station and wash down pad is provided for chemical deliveries. Fluoride flow is controlled through a peristaltic metering pump and injected into the Landsburg Tunnel.

Fluoride (Hydrofluosilicic Acid) Storage at Landsburg

Lake Youngs Algae Blooms

By fluoridating at Landsburg, water with a fluoride residual is fed into Lake Youngs. Fluoride is a “conservative” chemical, meaning that it does not dissipate into the environment. Therefore, the amount of fluoride added to the water system will stay in the water system all the way to the point of end use.

SPU adds fluoride in the form of hydrofluosilicic acid, which is by far the most economical form of fluoride for large water systems. However, hydrofluosilicic acid is a byproduct of the phosphate fertilizer industry and contains a trace amount of phosphorus impurities. It has been estimated that the phosphorus in the fluoride contributes about 20 percent of the phosphorus entering Lake Youngs. Lake Youngs is a phosphorus-limited lake, meaning that the algae growth is limited by the amount of phosphorus in the water. Therefore, the fluoride being added at Lake Youngs is partially contributing to the growth of algae in the lake.

Algae blooms in Lake Youngs are normal and occur at least once in most years. Until recently, they have not caused any issues except for seasonal taste and odor complaints, and those have been significantly reduced with the addition of ozonation as part of the 2004 Cedar Treatment Facility upgrades.

In 2008, the typical algae bloom in Lake Youngs changed in character, becoming filamentous and stringy. The stringiness of the algae caused several treatment plant shutdowns due to in-plant clogging, and has necessitated about $250,000 in treatment plant upgrades to address algae clogging.

Algae Growth Clogging the Cedar Treatment Facility in 2008

The algae also passed through the treatment plant, affecting water customers by clogging water meters and control valves. The meters and valves had to be cleaned more frequently than during normal periods. There is also an ongoing investigation if the clogging affected the accuracy of water meters, causing them to under- or over-read.

Algae Growth Clogging Downstream Facilities (left photo = wholesale meter screen; right photo: strainer for pressure reducing valve)

SPU was able to minimize the algae clogging during some of the bloom by bypassing the lake; water can be delivered from Landsburg directly to the Cedar Treatment Facility, but only when the water quality in the river is good enough to do so. In 2008, the lake was bypassed for approximately the last 1/3 of the algae bloom. Water quality in the river was not good enough to bypass the lake for the middle 1/3 of the algae bloom, and SPU was not aware of any clogging potential of this algae for the first 1/3 of the bloom. 2009 had a fairly minor bloom, without significant impacts. In 2010, SPU was able to bypass over half of the algae bloom, with much more bypassing possible had SPU better understood the clogging potential during periods in which bypass was thought not to be necessary.

A 2009 Lake Youngs Expert Review Panel was convened to study the issue and make recommendations on what could be done to minimize nuisance/clogging algae growth in the lake. The panel noted that the fluoridation of water entering Lake Youngs resulted in a relatively significant phosphorus load to the lake, increasing the potential for phosphorus-driven algae blooms. The Panel recommended moving the point of fluoride addition to downstream of Lake Youngs, thereby reducing the phosphorus load (and algae growth potential) to Lake Youngs by about 20 percent.

The Panel suggested that reducing the phosphorus load by 20 percent could “re-set” the algae growth potential in the lake to a lower level for several years; however, they also cautioned that it was very difficult if not impossible to predict the long-term behavior of the lake.

LONG-TERM ALTERNATIVES FOR FLUORIDATION

This study evaluated two alternatives for fluoridation on the Cedar River water supply.

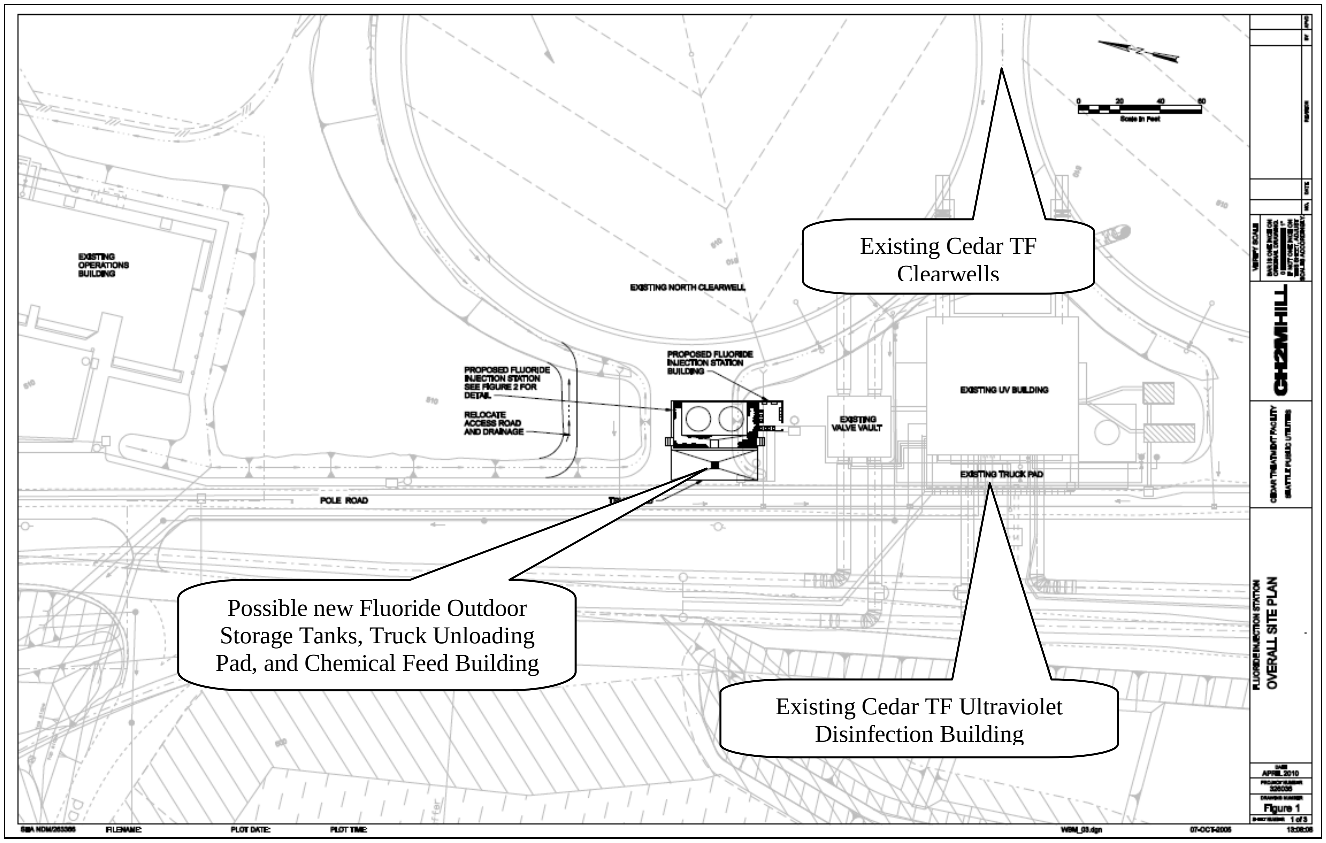
1. Maintain Fluoridation System As Is

This alternative is to maintain the status quo. Fluoridation would be continued at Landsburg with the existing facilities and staff. The existing facilities are in good condition and do not require any significant work to stay functional for many more years.

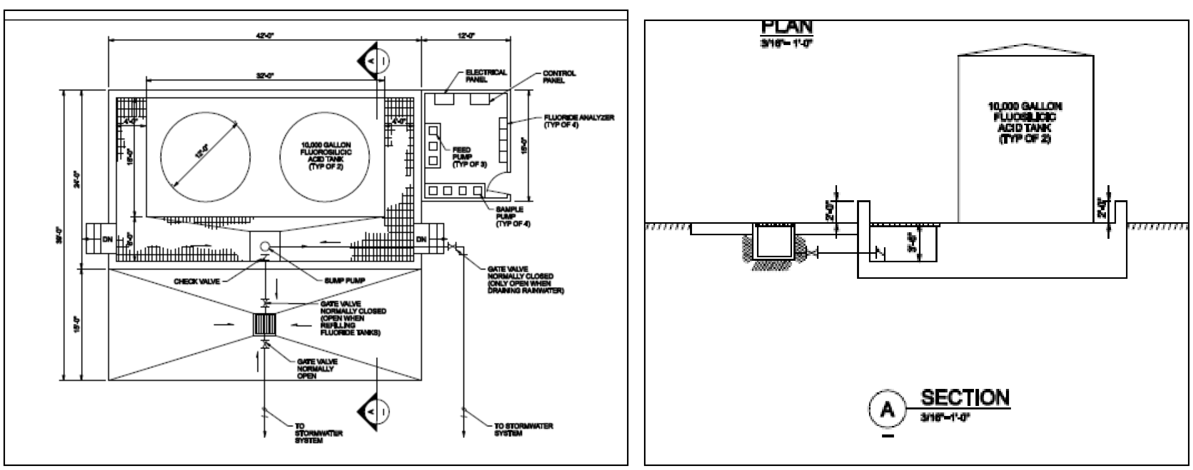
2. Move Point of Fluoride Addition to Lake Youngs

This alternative is to move the point of fluoridation to Lake Youngs, to be fed downstream of the lake. The facilities would be fairly simple, very similar to the Landsburg facilities: outdoor storage tanks on a double containment concrete pad, truck unloading station, and a small building for chemical feed pumps and controls.

CH2M HILL, the contractor operating the Cedar Treatment Facility as part of a Design-Build-Operate (DBO) contract, was asked to develop planning-level capital and O&M costs for a new fluoride facility to be incorporated into existing treatment facilities.



Potential New Fluoride Facilities at Lake Youngs (Site Map)



Potential New Fluoride Facilities at Lake Youngs (Plan and Section)

For the purposes of this analysis, the cost estimates from CH2M HILL are used with only minor modifications to account for SPU's typical levels of internal staff costs for capital projects. It is possible that the cost estimates could change, particularly if SPU were to implement the alternative using conventional bidding methods instead of through the existing DBO contract and/or to operate and maintain the fluoride facilities with existing SPU staff (such as SPU staff at Landsburg).

EVALUATION OF FLUORIDATION ALTERNATIVES

The fluoridation alternatives were combined with the shortlisted chlorination alternatives due to a few potential synergies between the alternatives. The next section describes the combinations of alternatives and the analysis of their costs and benefits.

Cost Analysis

The estimated capital and O&M costs are summarized in Table 3-1 below. The total present worth and annualized costs are calculated over a 50 year period. The economic assumptions are listed in the appendices, along with the line-by-line cost breakdowns.

In addition to capital and annual fluoridation costs, Risk Costs for fluoridation were estimated as follows: the baseline risk cost of not moving fluoride was estimated as the cost of 20 SPU and wholesale customer staff needing to spend 4 hours per day for one month cleaning clogged meters, control valves, and analyzers. It was further assumed that nuisance algae blooms would occur every other year, last about two months, but SPU would be able to minimize algae impacts about half the time by bypassing Lake Youngs.

Another cost could have been included: some of the wholesale customers have been claiming to experience water meter inaccuracies associated with algae clogging. Any inaccuracies would lead to either under- or over-billing for water use. Limited data suggests that the extent of the issue is not well understood yet, and more data is being gathered. For this reason, effects of potential metering and billing inaccuracies were not included in this analysis.

Moving the point of fluoridation to downstream of Lake Youngs was assumed to reduce the impacts by 20 percent, which is the proportional reduction in phosphorus to Lake Youngs achieved by moving the point of fluoridation. Risk was costed out as an incremental risk cost, meaning that the alternative of moving fluoride was assigned a zero risk cost, with the status quo alternative being assigned the higher risk associated with more phosphorus (algae growth potential) being added to Lake Youngs.

Table 2-1. Overall Cost Comparison (50-year Period)

Alternative	Capital Cost	Annual O&M	50-Yr Present Worth O&M	50-Yr Present Worth Risk Cost	Life Cycle Cost (PW Capital and 50-Yr O&M)
1. Leave Fluoride As Is	$0	$5,000	$91,000	$335,000	$426,000
2. Move Fluoride to Lake Youngs	$3,098,000	$107,000	$1,953,000	$0	$5,051,000

Recommendations for Fluoridation

The lowest life-cycle cost alternative is Alternative 1, status quo. This is because Alternative 2 has a high capital and annual cost relative to Alternative 1, and the reduced level of risk for Alternative 2 is not enough to offset the additional cost.

No recommendation for fluoride is given yet, due to the potential synergies between chlorination and fluoridation upgrades; the next section combines fluoridation and chlorination alternatives in order to make a recommendation about the combinations of those alternatives.

Note that there is a large difference in the life cycle cost between the two alternatives. That is due to the large capital cost of moving the point of fluoride addition to Lake Youngs compared to the relatively low quantifiable amount of risk reduction associated with the move.

In the future, should additional study result in better quantifiable impacts, then this decision should be revisited. Examples of these quantifiable impacts could be: direct impact of fluoride addition on algae growth in Lake Youngs; better correlation between algae growth and customer water meter inaccuracies / underbilling; and other changes such as the assumed number of labor hours and frequency of cleaning of meters and valves.

3. OVERALL ANALYSIS AND CONCLUSIONS

COMBINING CHLORINATION AND FLUORIDATION ALTERNATIVES

Six combinations of fluoridation and chlorination alternatives were carried forward for analysis. The fluoridation alternatives included status quo and moving the point of fluoride addition to Lake Youngs. The chlorination alternatives included status quo, enclosing the chlorine facilities and adding an emergency treatment scrubber, and replacing the chlorine gas system with a 12 percent liquid sodium hypochlorite system.

Cost Analysis

The estimated capital and O&M costs are summarized in Table 3-1 below. The total present worth and annualized costs are calculated over a 50 year period. The economic assumptions are listed in the appendices, along with the line-by-line cost breakdowns.

The capital, annual, and risk costs for the chlorination and fluoridation portions of each alternative are as stated in the previous sections of this document (in Tables 1-2 and 2-1).

Table 3-1. Overall Cost Comparison (50-year Period)

Alternative	Capital Cost	Annual O&M	50-Yr Present Worth O&M	50-Yr Present Worth Risk Cost	Life Cycle Cost (PW Capital and 50-Yr O&M)
1. Leave Fluoride As Is, Leave Chlorine As Is	$288,000	$85,357	$1,558,000	$8,166,000	$10,012,000
2. Leave Fluoride As Is, Add Chlorine Gas Scrubber	$2,233,000	$101,941	$1,861,000	$3,214,000	$7,308,000
3. Leave Fluoride As Is, Switch from Chlorine Gas to 12% Hypo (New Hypo Facilities)	$2,106,000	$236,495	$4,317,000	$335,000	$6,758,000
4. Move Fluoride to Lake Youngs, Leave Chlorine As Is	$3,386,000	$187,357	$3,420,000	$7,831,000	$14,637,000
5. Move Fluoride to Lake Youngs, Add Chlorine Gas Scrubber	$5,331,000	$203,941	$3,723,000	$2,879,000	$11,933,000
6. Move Fluoride to Lake Youngs, Switch from Chlorine Gas to 12% Hypo (Reusing Fluoride Facilities)	$3,692,000	$330,465	$6,033,000	$0	$9,725,000

Sensitivity Analysis for Risk Cost

The assumed risk costs for the alternatives are based on a lack of knowledge on what will happen in the future. Therefore, it is worthwhile to perform a sensitivity analysis to see if there is a point at which the lowest life cycle cost alternative, Alternative 3, will no longer become the lowest life cycle cost alternative.

The single most variable risk cost is associated with the risk cost for a major chlorine gas release. The costs in the table above are based on multiplying estimated damage costs by a 10 percent chance of such an event happening in a 100 year period (it should be noted that no such events have ever occurred for the City of Seattle). If a scrubber and building enclosure are added, then the risk is assumed to decrease by a factor of 10.

Based on the economic analysis, if the risks are assumed to be higher than 4 percent in a 100 year period, then Alternative 3 is still the lowest life cycle cost alternative. If the risks are assumed to be lower than 4 percent in a 100 year period, Alternative 1 becomes the lowest life cycle cost alternative.

As a sensitivity analysis, historical data was found and analyzed. The results, explained below, show that the assumed probability of 0.1% per year (10% per 100 years) falls within the range of historical data.

The first estimate used historical data on chlorine gas releases per state (associated with water utilities) as well as the number of utilities using chlorine gas in the US. This information, along with data from AWWA and EPA plus a couple of assumptions was entered into an SPU Probability Calculation Model . Releases with injuries were approximately 0.5 significant incidents per year per state. Depending on the assumptions made, this works out to a 0.02% to a 0.2% chance per year of a major release, or 2%-20% chance of a major release in 100 years. The lower end of these results in a higher NVP for Option 1 while the higher end has the highest NPV for Option 3.

The second estimate was also made using the United States National Library of Medicine TOXNET program information on water treatment facility chlorine leaks. Based on a search, between 0 and 4 major releases of chlorine per year for the last 10 years have occurred (averaging 2 per year). Using this information in the Probability Calculation Model it works out to about a 0.02% chance per year of a major release for a single utility, or about 2% chance of a major release in 100 years.

Given the significant potential for liability and poor ability to accurately predict future risk, **Alternative 3, which has a higher capital and O&M net present value that Alternative 1, should be favored over Alternative 1, which has a potentially very high risk cost.**

Sensitivity Analysis for Economic Assumptions

A sensitivity analysis was also performed for the assumed discount rate (3 to 7 percent). It showed that Alternative 3 has a positive net present value for this range of discount rates.

Recommendations for Fluoridation and Chlorination

The lowest life cycle cost alternative is recommended: Alternative 3, status quo for fluoride and convert from chlorine gas to 12 percent liquid sodium hypochlorite.

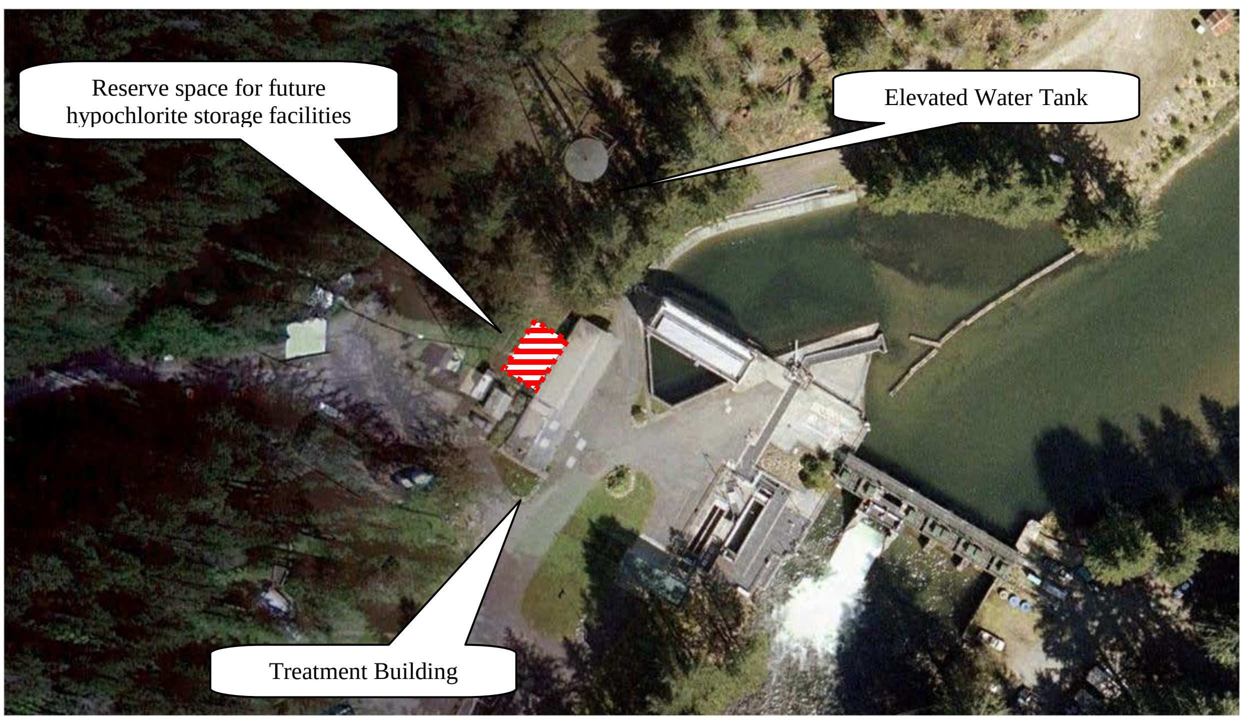
Alternative 3 has the lowest life cycle cost, followed by Alternative 2. Alternative 2, the chlorine gas scrubber alternative, has a slightly higher capital and a lower O&M cost than Alternative 3, and the higher risk costs (safety issues and future chlorine gas regulations) offset those slightly higher capital and lower O&M costs. Alternative 2 also requires modification to the 60-year old building to bring it up to current codes; depending on the local building permit official and fire marshal, the planning-level costs for enclosing the building could be very different from those shown herein. Alternative 2 also carries the risk that in the future regulations will preclude the use of chlorine gas. For these reasons, Alternative 2 is not recommended unless SPU is willing to live with those uncertainties.

Alternative 1 is not recommended because it only becomes cost-effective when risks of a major release are set low enough to make this author unwilling to live with the assumptions behind those poorly-defined and difficult-to-quantify risks.

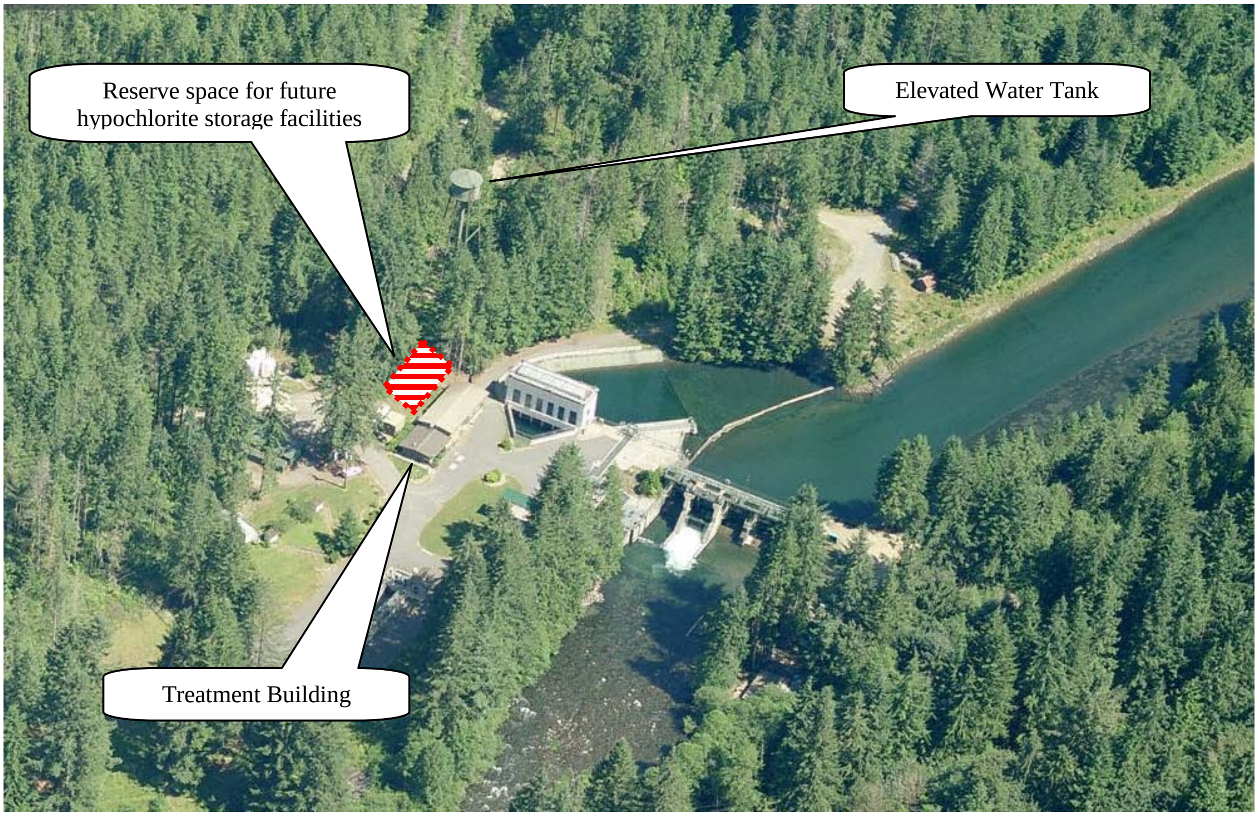
As described in the previous section, the additional costs of moving the point of fluoride addition to downstream of Lake Youngs currently outweigh the potential reduced level of nuisance / clogging algae blooms. This is true even if moving fluoride to Lake Youngs allows for the existing fluoride facilities to be re-used for liquid sodium hypochlorite. However, should future data enable better quantification of algae impacts (direct effect of fluoride on algae growth, direct effect of algae growth on metered revenues, etc) then this decision should be revisited. In the meantime, bypassing Lake Youngs during algae blooms (when possible) will limit the impact of algae on the water system.

Because the recommended alternative, bulk hypochlorite, does not require a continuous supply of pressurized water, the elevated water tank is not needed. It can be decommissioned (drained, exterior re-coated and then left standing empty, for use as an occasional backup water supply) without any new water supply facilities replacing it. The existing river pumps can be used to supply hypochlorite dilution water as needed.

The following figure indicates an area adjacent to the treatment building to be set aside for future hypochlorite storage facilities.



Space to be Set Aside for Future Chlorine Gas Scrubber

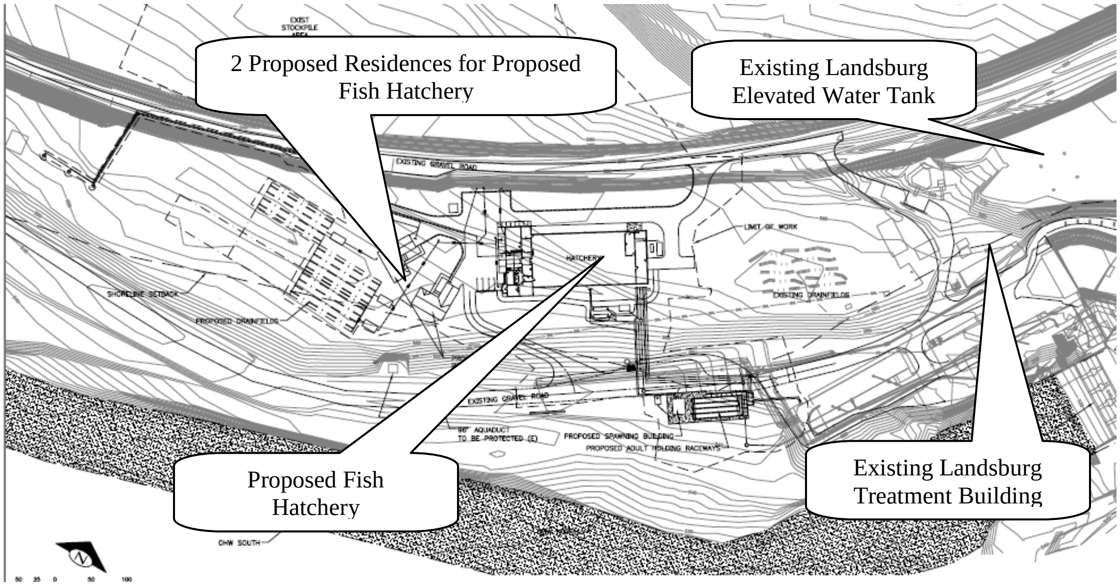


Alternatively, the area where one-ton cylinders of chlorine gas are stored could be re-purposed for sodium hypochlorite storage tanks, as long as the roof over that area is removed to allow for the height of the storage tanks. However, this approach would either require temporary hypochlorite facilities during construction, or no chlorination of the diverted water during construction.

As a side recommendation, part of the proposed fish hatchery is to drill a new well for potable water needs on site. This new potable water supply should be considered for possible connection to the existing Landsburg facilities for their potable water supply, including consumption, laboratory water, and eyewash/shower. Otherwise, a new well will have to be drilled to provide potable water for these purposes.

Another side recommendation is that the water supply for fire fighting should be confirmed with the local fire department. The existing vertical turbine pumps can be used for nominal fire suppression needs, but a larger pumping system might be needed to meet current codes and requirements.

One final footnote should be mentioned here: the proposed Cedar River Fish Hatchery is slated to be located immediately adjacent to the existing Landsburg facilities. The proposed hatchery includes two permanent residences for operators, staffing the facility continuously, and their families. If for some reason Alternative 2 is pursued, then safety considerations, such as chlorine awareness and evacuation procedures, should be reviewed extensively with any personnel associated with the hatchery operations. Alternative 3 does not have this requirement.



Proposed Residences at Proposed Fish Hatchery at Landsburg