Olympic Pipe Line Company

16” - Bellingham & Vicinity
Block Valve & Check Valve
Effectiveness Evaluation
October 27, 1999
Revised December 12, 2000

MARMAC Project #2829

OLYMPIC PIPE LINE COMPANY

16”- Bellingham & Vicinity Block Valve & Check Valve Effectiveness Evaluation

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October 27, 1999
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PREFACE

This document supersedes and replaces the *16”- Bellingham & Vicinity Block Valve and Check Valve Effectiveness Evaluation* dated October 27, 1999, which was previously issued to the City of Bellingham. The revision date of this document reflects the latest date that is applicable to work performed in the selection of new valve placements and existing valve modifications. Other revisions to the text may have been made at a more recent date.

This Evaluation has been expanded to include enhancements, clarifications and additional information as outlined below:

- Transient-release volume estimations have been re-calculated using a rigorous hydraulic model as provided by Stoner Associates, Inc. These volumes are released prior to full closure of the block valves. This calculation method is more accurate than the previous method.
- A check valve has been added at milepost 16.76 for additional protection to central Bellingham.
- Drainage sections have been re-numbered to coincide with those used in the 16” Ferndale to Allen Evaluation.
- The following total release-volume comparisons have been made for a severed-pipeline failure and for a large leak: 1) “Existing Valves vs. Existing + New Valves” for a 10-minutes transient release, 2) “Existing Valves vs. Existing + New Valves” for a 5-minutes transient release, and 3) “5-minutes vs. 10-minutes Transient Release” for “Existing + New Valves”.
- The Heavier-Than-Air Vapor Analysis section has been supplemented to further clarify the conservative nature of the original analysis.
- Graphs of the elevation profile and potential release volume profiles for this section of pipeline have been combined into a single document for easier comparison. Release profiles include three cases: 1) “No valves”, a hypothetical case; 2) “Existing valves”, the valves present at the time of the 1999 Bellingham incident; and 3) “Existing plus new valves”, which includes the “existing” valves plus the new valves installed or scheduled to be installed as a result of this Evaluation.

The Bellingham area covered by this Evaluation is part of the Ferndale-to-Allen section of the pipeline, for which a separate report has been prepared. These Evaluations are consistent with one another as relates to valve implementation and calculated potential static-release volumes. Should any changes be made to the Bellingham Evaluation with regard to valve placements, revision of the Ferndale-to-Allen Evaluation will be necessitated.

MARMAC Engineering

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1.0 INTRODUCTION

This evaluation is a review of the Olympic Pipe Line Company (OPL) 16” refined products pipeline within the Bellingham, Washington area. “Bellingham and vicinity” includes a 10.8-mile segment of the 16” pipeline from Ferndale Station to Allen Station. It includes the area between the following pipeline crossings: approximately ¼-mile N of Kline Road, at pipeline MP-10.51, to approximately ½-mile N of Roy Road, at pipeline MP-21.45. This section of pipeline has been evaluated with regard to the effectiveness of the existing block valves and check valves in the protection of sensitive resources that may be impacted by a pipeline release. Title 49, Code of Federal Regulations, Part 195, Section 195.260 (c) of the Federal Pipeline Safety Standards for Hazardous Liquid Pipelines require that a valve be installed on each mainline at locations that "will minimize damage or pollution from accidental hazardous liquid discharge, as appropriate for the terrain in open country, for offshore areas, or populated areas”. All block valves considered for addition to the pipeline are remotely controlled valves (RCV). Consideration is also given to the installation of new check valves (CV), and to the addition of remotely controlled actuators to any existing hand-operated block valves (HOV) to satisfy these guidelines.

Evaluating the spacing and effectiveness of the existing valve sites on this segment of pipeline entailed the following steps:

- Evaluation of drainage paths and destinations on topographical maps, resulting in predicted drainage footprints, for a pipeline release of sufficient volume if it were to occur at any point along this pipeline segment.

- Identification of Sensitive Resources, where a greater level of loss control may be warranted.

- Development of a pipeline elevation vs. milepost (MP) profile (graph) for the OPL Ferndale-to-Allen pipeline section, in the Bellingham area (MP-10.7 to MP-21.5).

- Determination of potential liquid-release volume (valves closed) for a major pipeline failure at selected points along this pipeline segment, if it were to occur. Two release types are reviewed: A large leak; and a “guillotine” failure, which is a complete separation of the pipeline, resulting in a leak of maximum rate.

- Consideration of the addition of new valves and the modification of existing valves in order to effect a greater level of loss control where warranted, and calculation of the revised release volumes with inclusion of these valves.

- Determination of “critical” valve locations.

- Installation of an independent major leak detection system, in accordance with the “Pipeline Safety Immediate Action Plan,” to augment the existing system.

Results of this evaluation are shown in Appendices A, B & C, and Tables 1 through 5. The maps in Appendix-C are organized by milepost number. Identified on each map are the following:

- Pipeline alignment,

- Location and type of valves,

- OPL Mileposts,

- Sensitive resources, including but not limited to environmentally sensitive features, population and business centers, schools and hospitals within a one (1)-mile corridor of the pipeline, and

- Drainage footprints, showing the predicted path to be followed by a release of sufficient volume.

A heavier than air vapor analysis has also been included. This vapor analysis has been performed at the request of the City of Bellingham. Due to variations in the terrain and atmospheric conditions, the vapor analysis did not affect the results of other portions of the valve effectiveness evaluation.

The Department of Transportation’s Research and Special Programs Administration (RSPA) issued an amendment to 49 CFR Part 195 that takes effect on March 31, 2001. It requires hazardous liquid pipeline operators with more than 500 miles of pipeline to assess and validate the integrity of their pipeline segments that could affect "high consequence areas" (HCA). The new amendment also defines the criteria to be used for identifying HCA's. The work to prepare this Valve Effectiveness Evaluation was initiated and substantially completed before these new Pipeline Safety regulations were finalized. Although all sections of the pipeline were evaluated, it should be noted that only specific sensitive resources were examined in this evaluation, rather than all the components discussed in the final rule defining HCA’s.

2.0 METHODOLOGY

The analysis was divided into the following tasks, summarized below.

Drainage Analysis – The drainage analysis described in Section 5.0 is conducted by drawing the pipeline route on United States Geological Survey (USGS) quadrangle maps. Then the maps are used to predict the flow path of product if it were to be released anywhere along the pipeline route. Results of the analysis are then drawn on the same maps.

Identification of Sensitive Resources – Some of the sensitive resources within a 1-mile corridor along each pipeline right-of-way (ROW) are plotted on the maps showing the pipeline routes, in Appendix-C.

Elevation Profile – The elevation profile for the pipeline is graphically depicted using data points obtained from OPL pipeline alignment sheets. Although the data points attempt to recreate the basic profile of the pipeline, the profile does not account for all minor curvatures in the terrain. Locations and types of “existing” valves are indicated on the profile. “Existing” valves are those which were present at the time of the 1999 Bellingham release incident. The profile is then utilized to establish an Excel spreadsheet for the calculation of potential static-release volume at each data point. Review of the elevation profile also assists in the selection of sites for new or modified valves after the release analysis has been performed for the “existing” valves. The selected new or modified valves are then added to the profile. The elevation profile is graphically depicted in Appendix-B.

Release Analysis and Valve Selection – The potential static-release volumes for each data point are calculated for the existing valves and the results are tabulated. A static-release volume profile, showing locations of existing valves, is used to assist in the evaluation. Sensitive resources identified on the maps are then compared with the tabulated and profiled release data. Locations requiring additional protection are identified, new and/or modified valve locations are selected, and calculations are then performed to include the existing and the proposed new and/or modified valves. These results are then compared to those for only the existing valves in order to determine the level of improvement obtained. The selected new and/or modified valves are then displayed on the elevation profile. Release volume profiles are graphically depicted in Appendix-B.

Heavier than Air Vapor Analysis – Analysis has determined that gasoline is the only product transported by the pipeline with the potential to produce flammable vapors that can drift or blow away from the site of a potential spill. The physical parameters used for the gasoline analysis were derived primarily from material-safety data sheets (MSDS) for gasoline. A review of two unleaded grades of gasoline determined that the physical parameters needed for modeling releases of gasoline are similar for the various types of gasoline. The evaporation rates used for the gasoline analysis were derived from the Automated Resource for Chemical Hazard Incident Evaluation (ARCHIE) computer model. Section 7.0 contains a more detailed discussion of ARCHIE. Evaporation rates were developed for several environmental conditions, including temperature and wind speed. ARCHIE was then used to calculate the distance that the gasoline vapor cloud could travel before its concentration falls below the lower flammability limit (LFL) of gasoline vapor. Below this limit, the air-vapor mixture is no longer combustible. This model utilizes a methodology specifically designed for heavier than air vapor analysis. Various cases were also examined to account for spill pool size and environmental conditions, e.g. wind, temperature, and stability. Information on wind direction and speed for the Georgia-Pacific site in Bellingham was obtained from the Northwest Air Pollution Authority and is assumed to be representative of the Bellingham area.

3.0 PIPELINE RELEASE VOLUMES

This evaluation follows the precepts of a report titled “Hazardous Liquid Pipeline Risk Assessment” by California State Fire Marshall dated March 1993, regarding the effectiveness of block valves on release volumes from liquid pipelines. It states that a block valve’s effectiveness is related to the physical proximity of the release point to the valve, the pipeline elevation profile, and the time required to close the valve once a pipeline release has been identified. A block valve would be effective in minimizing the static drain-down portion of a release caused by a leak located immediately down-slope from it, assuming it is readily closed. On the other hand, in many cases it would have no effect on the drain-down portion of a release immediately up-slope from it, even if it could be immediately closed. It can also be concluded from the report that: block valves downstream of a leak do not reduce pipeline release volumes caused by continued pumping; downstream block valves are effective only in reducing the drain-down component of a pipeline release; and block valves are not effective in significantly reducing the total pipeline release volume unless the release can be quickly identified for pipeline shut-down and block valve closures.

The total volume released by a pipeline failure includes two components:

1) Transient volume - the liquid released prior to full closure of the block valves, and
2) Static volume - the liquid that drains from the pipeline after the block valves are fully closed.

Transient release volumes are included in this evaluation at the request of the City of Bellingham, for determination of total release volumes. Transient release volumes, however, are not used herein for the selection of new block valve sites.

The transient release volume is primarily affected by the leak size, the pipeline operating pressure at the leak point, and the time required for leak detection and full closure of the RCV’s. It may also be affected by the type of valve(s) influencing any given release, either check or RCV. The check valves close automatically upon pipeline flow reversal, which would be initiated by a sufficient upstream leak or pipeline shutdown, whereas the RCV's have a 2-minute closure-cycle time. This closure time is in addition to the detection and response times required prior to initiating the valve closures. The transient component considers the leak detection time, the signal evaluation time, the operator's response times to shut off the pumps and initiate valve closures, and the RCV closure cycle time of 2-minutes. Normal operating procedures require the pumps to be shut off prior to initiation of valve closures.

Transient releases were modeled by Stoner Associates, Inc. using a rigorous computer hydraulic analysis, taking into account the pipeline operating pressure and the compressibility of the liquid. The transient release point was modeled for two different types of release: a large pipeline "hole" in one model ("large leak"), and a pipeline rupture in another model ("guillotine failure," or "severed pipeline release"). Both types are considered as a "major" leak. A guillotine failure results in a leak of maximum rate. The flow coefficients (C_v) used in the calculations were 150 for a large leak, and 80,000 for a guillotine failure. The use of these two cases helps to illustrate the effect of a leak's size on the transient release volume. A flow coefficient is defined as the volume in gallons per minute that would pass through the "hole" in the pipeline if the change in pressure across the hole were one (1) pound per square inch (psi). It is used herein as a means of comparison. The actual flow depends upon the actual change in pressure from inside-to-outside of the pipe. Transient release calculations are based on these actual pressures.

Pipeline operating pressure affects the initial transient-release rate. As depressurization of the pipeline occurs, the product initially accelerates to a higher flow rate as it exits the pipeline, followed by a declining flow rate as the pipeline pressure is reduced. Pipeline release may then stabilize at a rate slightly greater than the initial pumping rate until the pumps are shut off. Alternatively, if the pumps "trip off" on low suction pressure the pipeline release will quickly drop, after depressurization, to a rate significantly less than the initial pumping rate. For transient and total release calculations, the initial pumping rate is assumed to be at the pipeline design capacity, 9,272 barrels per hour, with gasoline. Design capacity is based upon operation at the maximum allowable operating pressure (MAOP) of the pipeline. Gasoline has the highest pumping rate of any pipeline product, hence, the greatest potential transient release volumes.

Leak response timing was based on an existing supervisory control and data acquisition (SCADA) pipeline leak-detection system (PLDS), backed up by the implementation of a new, independent major rupture-detection system (IRDS). The IRDS is supplied as required by the “Pipeline Safety Immediate Action Plan,” and is independent from the existing SCADA system. SCADA is used to monitor the pipeline and to control the RCV’s. The IRDS is designed to discriminate between a large pipeline release and normal flow variations in pipeline operation, facilitating a more rapid operator response to a release. Response was evaluated for total-response time intervals of both 5-minutes and 10-minutes; that is, from initiation of a leak to full closure of the RCV valves. This is defined as the transient duration of the leak. Five minutes is anticipated to be close to a minimum response time. The 5-minutes duration is approximated as follows: 1.5 minutes to detect a leak + 0.5 minute to shut off the pumps + 1.0 minute to initiate the RCV valve closures + 2.0 minutes to fully close the valves. Ten minutes is selected as a more typical response time. The 10-minutes duration is approximated as follows: 1.5 minutes to detect a leak + 3.0 minutes to shut off the pumps + 3.5 minutes to initiate the RCV valve closures + 2.0 minutes to fully close the valves.

The static release volume, or drain-down volume, at any given point includes only the liquid in the upstream and downstream segments of pipe that is available to be released at that point by gravity-flow only, were a leak to occur. These volumes are initially located at elevations higher than or equal to the release point elevation and are, by definition, always isolated between two fully closed valves. These valves are 1) the nearest RCV valve upstream of the release point, and, 2) the nearest RCV or check valve downstream of the release point. The static volume component is independent of the pumping rate and does not include the volume of liquid in depressed areas of the pipeline that trap the liquid. In Figure 3-1, the upstream static component includes the volume of liquid in Sections-A and -C of the pipe. The upstream static component does not include the volume of liquid trapped in Section-B of the pipe. The static release volume at any given release point is affected by the locations of the block valves and check valves, and by the topographical features between those valves. Although Figure 3-1 shows only the segment of pipeline upstream of a potential release site, the downstream static component is determined by the same method as the upstream static component.

In this evaluation, the transient and static components are numerically added, at any given data point, to arrive at the total release volume. However, it is possible that the isolated segment of pipe upstream and downstream of the release point could partially drain during the transient phase, before the valves fully close. This introduces a measure of conservatism into the static- and total-release volume calculations herein because these calculations assume that any isolated segment of pipe is full of liquid.

The elevation profile of the pipeline is plotted using OPL pipeline alignment sheets. This profile is used to set up the static-release volume spreadsheet with the mileposts, associated elevations, high and low points, pipe lengths, valve locations, and sensitive resources descriptions.

Valve selections and locations are based upon the static release volumes only. Transient release volumes are much less affected by valve placements and are not used herein to determine new valve locations. As a comparison for the effectiveness of the existing and new valves, static release volumes for the “existing” and the “existing plus new” valve cases are graphically depicted in Appendix-B. These graphs plot the potential static-release volume at each milepost location based upon complete loss of liquid from the pipeline. In the majority of cases, the flow of product from most pipeline leaks will not be from a complete line-separation failure or “guillotine release,” but from a smaller opening in the pipeline system. In this case, static drain-down would be at a lower rate than that observed in a guillotine failure. A lower static-release rate may facilitate plugging of the pipeline at the leak point by OPL response crews during pipeline drain-down, prior to complete loss of product from the isolated line segment. This may result in lower static and total release volumes.

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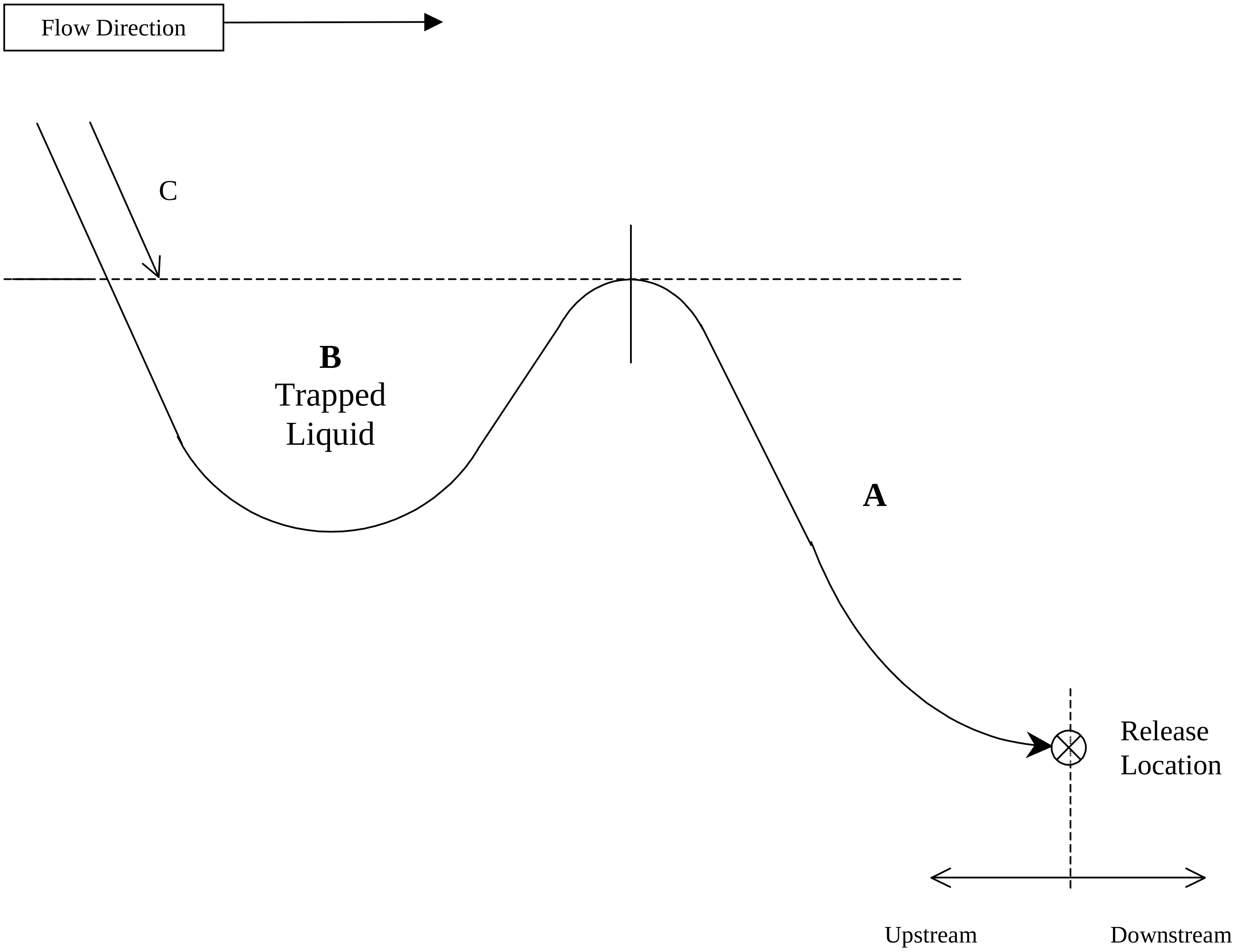
FIGURE 3-1, STATIC RELEASE COMPONENTS



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Pipeline releases were postulated at selected points along the pipeline in the Bellingham vicinity in order to determine potential release volumes at those points. The segments of pipeline in the Bellingham vicinity are those which have the potential to spill directly within, or drain through, the city limits of Bellingham. For this evaluation, the pipeline in the Bellingham vicinity includes OPL mileposts MP-10.7 through MP-21.5.

The Appendix-A spreadsheets tabulate the calculated static release volumes for three static release conditions. The first condition, “No Valves,” shows the calculated release volumes at identified points on the pipeline assuming there are no valves to isolate a leaking segment. The second condition, “Existing RCV’s and Check Valves,” shows the calculated release volumes at identified points on the pipeline assuming closure of only the “existing” RCV block valves and check valves. The third condition, “Existing + Converted & New RCV’s and Check Valves,” shows the calculated release volumes at identified points on the pipeline assuming closure of all RCV block valves and check valves, both “existing” and “new”. “Static and Transient Release Data” is also tabulated in Appendix-A to show Total Release Volumes for several cases of “Existing Valves” vs. “Existing + New Valves”, for varying response times and pipeline failure sizes. Although there are none in the Ferndale to Allen section of the pipeline, any HOV block valves are always assumed to be in the “open” position when calculating static release volumes. Results of the Appendix-A spreadsheets are graphically displayed in Appendix-B.

Potential Release Volume Calculation

The following is a typical procedure of the release volume calculation:

Point-to-point volume = (Length of pipe) x (Inside section area of pipe)

Where,

Length of pipe $= [(\Delta \text{ Elevation})^2 + (\Delta \text{ Distance})^2]^{1/2}$, and

Inside section area of pipe $= \pi$ (Inside radius of pipe, ft.)^2

$= \pi$ [(Outside diameter of pipe)/2-(Pipe wall thickness)]^2

After this “point-to-point” volume has been calculated for all points, the static-release volume at each point is calculated as follows:

Static release = [volume upstream of location] + [volume downstream of location] – [trapped volume upstream of location] – [trapped volume downstream of location]

Only volumes which could gravity flow to a given leakage location and contribute to a spill are used in this calculation. Trapped volumes, volumes contained in sections that are topographically isolated from the leak point and volumes that are isolated by valves from the leak point are not included.

For transient-release volumes, results were taken from the Stoner Associates hydraulic model.

Total release volume is calculated as follows:

Total release volume = (static release) + (transient release)

This same procedure applies to the calculations for the “existing valves”, and the “existing plus new valves” conditions. The “no valves” case was calculated for static release only. The static and total release volumes at each point can be found in Appendix-A. Transient volume is the difference between the total and the static volumes.

4.0 VALVE LOCATIONS

Review of block valve and check valve effectiveness in the Bellingham area utilizes the valves listed in Table 1. “Existing” valves were present at the time of the 1999 Bellingham pipeline failure on the Ferndale to Allen section, and “New” valves are those installed or modified as a result of this study completed since the pipeline failure. There are no existing hand-operated block valves (HOV) within these mileposts:

Table 1 - Valve Locations

Actual Milepost	*Valve Type*	*Operation*	*Valve Status*
8.10	Check Valve	Automatic	New
11.93	Block Valve	Remote Controlled	New
16.18	Check Valve	Automatic	New
16.18	Block Valve	Remote Controlled	Existing
16.76	Check Valve	Automatic	New
20.60	Check Valve	Automatic	New
22.02	Check Valve	Automatic	New

The new check valves located at MP-8.10 and MP-22.02 do not affect potential releases with flow paths through the Bellingham City limits and are therefore not critical to the City of Bellingham.

There are two valves located at MP-16.18. The new check valve at this milepost is installed on the upstream end of the existing RCV block valve, located on an up-sloping grade. This check valve, the check valve at MP-8.10 and the RCV at MP-11.93 were installed in accordance with the “Pipeline Safety Immediate Action Plan”. The check valve at MP-16.18 will provide a more rapid response than the existing RCV in case of an upstream major release.

The new valve sites and converted valve sites in the Ferndale-Allen section of pipeline were selected considering the abundance of sensitive resources within a 1-mile perimeter of the pipeline ROW, with emphasis on the abundance within the predicted drainage paths. Areas of abundant sensitive resources are compared with the static-release volume profile. New valves are added or existing HOV’s are converted in sensitive areas where volumes are comparatively high and significant improvements can be obtained.

The City of Bellingham has requested a ranking of critical valves. “Critical valves” are valves that could restrain liquid volumes that could potentially spill within or drain through the Bellingham City limits. “Critical drainage sections” are those portions of the pipeline that could spill within or drain through the Bellingham City limits. Valves and sections that do not meet these criteria are not deemed critical to the City of Bellingham. The critical valves can be ranked by the relative population that each valve assists in protecting and by the volume that the valve controls. Street density and USGS topographical maps were used to determine the affected population. Using these objective criteria, the rank of critical segments of the pipeline between MP-10.7 and MP-21.5 is determined, from Rank 1 as most critical, to Rank 9 as least critical.

Table 2 – Pipeline "Critical" Drainage Section Ranking

Rank	*Drainage Section*	*OPL Mileposts*	*Drainage Location*	*Valves Within Section*
4	10	10.7 – 11.5	Unnamed Stream	None
10	11	11.5 – 12.2	Depression Southwest of Pipeline	New RCV Block @ MP 11.93
6	12	12.2 – 12.8	Unnamed Stream	None
5	13	12.8 – 14.3	Squalicum Creek	None
1	14	14.3 – 15.8	Bellingham	None
2	15	15.8 – 16.7	Bellingham, Whatcom Creek	Existing RCV Block and New Check @ MP 16.18
3	16	16.7 – 18.7	Bellingham	New Check @ MP 16.76
7	17	18.7 – 19.2	South Bellingham	None
9	18	19.2 – 20.2	South Bellingham	None
8	19	20.2 – 21.5	Chuckanut Village	New Check @ MP 20.60

The above ranking does not account for the minor topographical features of the terrain surrounding the pipeline that are not apparent on the maps, or the makeup of the soil. Although a valve may not appear within a more critical section, e.g. Section 14, the best overall protection may be achieved by valve placement within another section, e.g. Section 15. All new valves affecting the critical sections of pipeline are either RCV block valves or check valves. These valves have quicker response times than hand operated block valves, thereby reducing the spilled volumes in case of a leak. Drainage sections represent the portion of the numbered sections between Ferndale Station and

Allen Station that affect Bellingham. The critical valves, in the order of ranking, are located as follows:

1. Existing RCV Block Valve and New Check Valve at MP 16.18,
2. New Check Valve at MP 16.76,
3. New RCV Block Valve at MP-11.93, and
4. New Check Valve at MP-20.60.

Three of these locations have only one valve, whereas the fourth location, MP-16.18, has both primary and secondary valves. The RCV at MP-11.93, although in a lower ranked section, has a higher valve rank than the check valve at MP-20.60 because it controls more volume over a longer potential release section.

The critical valves at MP-11.93 and MP-16.18 are remotely controlled valves. These valves are operated remotely via the existing SCADA system at the OPL Renton facility. In case of a pipeline release, the pumps will be shut down and these valves will be remotely operated to close.

At the critical valve location MP-16.18, a new check valve has been installed at the upstream end of the existing RCV block valve. This location is an uphill run of piping, suitable for a check valve. A check valve does not require remote control or a human operator to stop flow in the reverse direction. In case of a major leak upstream (down-slope) of these valves, this check valve will provide immediate containment, upon flow reversal, of the product residing in the downstream (up-slope) section from MP-16.18 to MP-16.76 while the RCV is closing. In case of a pipeline release in this area, this will provide immediate back-flow protection and reduction of the total spill volume into the populated area near Whatcom Creek. The new critical valves at MP-16.76 and MP-20.60 are also check valves.

5.0 DRAINAGE AND VALVE LOCATION ANALYSIS

Drainage Analysis

A spill of sufficient volume has the potential to find its way to a stream or river, and thence to a lake or bay. In order to determine the probable paths and destinations of product released along the pipeline in the Bellingham area, a drainage analysis was prepared. To conduct the analysis, USGS topographical maps of 1:24,000 scale (7.5-minute meridians) were obtained to cover the pipeline section from Ferndale Station to Allen Station. The resulting drainage “footprints” are shown in Appendix-C. Shaded areas adjacent to the pipeline indicate land areas that could potentially be impacted by an up-gradient spill. Flow lines within these areas indicate the likely drainage paths that would be followed by the liquid. Each shaded area converges to a stream path, directly impacts a water body, or encounters a barrier or depression. Table 3 indicates the destination and drainage path of potential spills at given milepost locations. Only liquid releases from Sections 10 through 19 could potentially flow within the Bellingham City limits.

The drainage path analysis does not consider valve locations, valve effectiveness, or potential spill volumes. It simply models a possible surface flow-path for any liquid of sufficient volume originating along the pipeline route. The actual fate of a given spill would depend upon the total volume and rate of release, the location, soil permeability and porosity along the drainage path, slope of the path, and other factors. A small “leak” may impact only the area local to the spill, whereas a “guillotine failure” near a river, stream, creek, or slough could impact a greater area. Specific considerations for each portion of this pipeline section are pointed out in the “Valve Location Analysis” discussion.

The analysis is interpretive in that it relies on the elevation contours on the USGS maps. The pipeline route was drawn on the maps with OPL milepost markers indicated. Then the topography, as well as the presence of streams, rivers, sloughs, etc., was examined to predict the probable drainage footprints for a liquid released anywhere along the pipeline route. The topographic elevation contour interval on the maps is 20 feet, although the 10 feet above sea level contour is included in some areas. The liquid is assumed to follow the gravitational path of least resistance (the steepest slopes) until a natural stream, a water body, physical barrier, or depression within a one-mile distance is encountered. When a stream is encountered, it is followed to its ultimate destination. Any features that are not apparent on the 7.5-minute maps are not considered in the analysis. However, the predicted drainage footprints and paths are believed to be reasonably representative of actual drainage conditions.

Releases that occur near developed areas have the potential to enter storm drains through openings along roadways. Developed areas are shown on the maps; however, actual locations of storm drains and storm drain openings have not been identified.

The “average” and “peak” release volumes in Tables 4A and 4B are calculated for each drainage section[1]. Analysis of the calculated “average” and “peak” release volumes in Tables 4A and 4B show, in Tables 5A and 5B, the effectiveness, or benefits of the additional new valves and valve conversions to the environmental areas. The new valves and conversions are shown to decrease both the “average” release volumes and “peak” release volumes.

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[1] A “drainage section” is defined as a section of pipeline where any liquid originating from a release within that section would follow the same drainage path.

TABLE 3 - SPILL DESTINATIONS AND PATHS FOR DRAINAGE SECTIONS

Drainage Section	*OPL Mileposts*	*Water Body Destination*	*Destination Location*	*Via Path*
10	10.7 – 11.5 N Bellingham	Bellingham Bay	Squalicum Creek outlet to bay	Squalicum Creek, via unnamed streams
11	11.5 – 12.2 N Bellingham	Possible pooling	Depression southwest of pipeline	Note: Overflow would run to Bellingham Bay as indicated in previous entry
12	12.2 – 12.8 N Bellingham	Bellingham Bay	Squalicum Creek outlet to bay	Squalicum Creek, via unnamed streams
13	12.8 – 14.3 N Bellingham	Bellingham Bay	Squalicum Creek outlet to bay	Squalicum Creek
14	14.3 – 15.8 Bellingham	Bellingham Bay	Bellingham	Whatcom Creek, via unnamed stream
15	15.8 – 16.7 Bellingham	Bellingham Bay	Bellingham	Whatcom Creek
16	16.7 – 18.7 Bellingham	Bellingham Bay	Bellingham	Whatcom Creek, via unnamed stream
17	18.7 – 19.2 S Bellingham	Bellingham Bay	S Bellingham	Padden Creek, via Lake Padden, via unnamed stream
18	19.2 – 20.2 S Bellingham	Bellingham Bay	S Bellingham	Padden Creek, via Lake Padden, via unnamed stream
19	20.2 – 21.5 Chuckanut Village	Chuckanut Bay	Chuckanut Village	Chuckanut Creek

The following release volumes are those having the potential to gravity-drain through the City of Bellingham. The volumes in Table 4A are static release volumes, that is, volumes released after full closure of the RCV’s and check valves. The static rather than transient releases are reviewed for the selection of new valve sites, since valve locations primarily affect the static release volumes. Static release volumes are “fixed”, that is they do not vary or change, for the selected valve locations and are not dependent upon the spill response time to close the RCV’s.

Table 4A - Static Release Volume

Bellingham & Vicinity Drainage Sections

Location		*Average Release [bbl]*			*Peak Release [bbl]*		
Drainage Section	*OPL Mileposts*	*No Valves*	*Existing Valves*	*Exist. + New Valves*	*No Valves*	*Existing Valves*	*Exist. + New Valves*
10	10.7 – 11.5	4,081	1,305	632	4,311	1,535	862
11	11.5 – 12.2	4,712	1,935	1,135	5,052	2,275	1,436
12	12.2 – 12.8	5,415	2,639	1,531	5,730	2,954	1,846
13	12.8 – 14.3	4,769	1,993	1,172	5,685	2,908	1,800
14	14.3 – 15.8	3,565	699	699	4,012	1,149	1,149
15	15.8 – 16.7	3,563	1,467	812	4,024	2,864	1,137
16	16.7 – 18.7	1,203	1,203	984	2,185	2,185	2,185
17	18.7 – 19.2	540	540	431	707	707	575
18	19.2 - 20.2	1,199	1,199	947	1,497	1,497	1,258
19	20.2 - 21.5	950	950	839	1,950	1,950	1,632

“Average” release is defined as the mathematical average of all the milepost release volumes evaluated within a given section. “Peak” release is defined as the single point of greatest value of all the milepost release volumes evaluated within a given section. It can be seen that the addition of valves has significantly reduced potential static-release volumes in this area. Appendix-B contains a point-by-point profile of the static release volumes.

Table 4B - Total Release Volume, Existing vs. Existing + New Valves

Bellingham & Vicinity Mileposts

For “Guillotine” Release (C_v = 80,000)
10-Minutes Transient Duration + Static
Case 4 & Case 8

Location				*Total Release [bbl]*					
Reference Drainage Section	*Actual Milepost*	*Description*	*Elevation [ft]*	*Case 4 Existing Valves*			*Case 8 Existing + New Valves*		
				Static	*+Transient*	***=Total***	*Static*	*+Transient*	***=Total***
10	10.98	South of Kline Rd. crossing	275	1,247	2,491	**3,738**	574	1,647	**2,221**
12	12.34	Stream @ Hannegal Rd. crossing	185	2,954	3,237	**6,191**	1,846	2,718	**4,564**
13	12.96	Squalicum Creek crossing	145	2,908	3,356	**6,264**	1,800	2,707	**4,507**
14	15.01	Alabama St. crossing	310	1,149	3,236	**4,385**	1,149	1,689	**2,838**
15	15.89	Whatcom Creek crossing	237	1,072	3,626	**4,698**	1,072	1,463	**2,535**
16	16.76	New check valve location	430	2,185	2,989	**5,174**	0	1,055	**1,055**
	18.56	Bellingham area high point	870	0	1,162	**1,162**	0	1,163	**1,163**
19	20.52	Chuckanut Creek crossing	365	1,578	2,757	**4,335**	1,259	2,322	**3,581**
	21.45	High point N of Samish Lake	825	152	1,465	**1,617**	152	1,352	**1,504**

After the new valve locations have been determined, based on the reduction of potential static-release volumes, the potential transient-release volumes are calculated. Addition of the potential static and transient volumes results in the potential total-release volume at any given point. A comparison of the total-release volumes is made in Table 4B, based on a 10-minute response time to fully close the RCV valves. They are the combined volumes released before plus after full closure of the RCV valves. Data is for the indicated milepost within each indicated drainage section. These total release volumes are dependent upon not only the block valve and check valve locations, but also upon the spill response time to fully close the RCV’s. A comparison of these cases is profiled in Appendix-B.

Table 5A - Effectiveness of New Valves On Static Release

Bellingham & Vicinity Drainage Sections

Existing Valves vs. Existing + New Valves

Location			*Average Reduction*	*Peak Reduction*
Drainage Section	*OPL Mileposts*	*Description*	*[bbl]*	*[bbl]*
10	10.7 – 11.5	Kline Rd. area	673	673
11	11.5 – 12.2	King Mtn. / Van Wyck Rd. area	800	839
12	12.2 – 12.8	King Mtn. / Van Wyck Rd. area	1,108	1,108
13	12.8 – 14.3	Squalicum Creek area	820	1,108
14	14.3 – 15.8	NE Bellingham, city limits	0	0
15	15.8 – 16.7	Whatcom Creek area, city limits	655	2,185
16	16.7 – 18.7	Adjacent to Lookout Mtn.	218	2,185
17	18.7 – 19.2	NE of Lake Padden	109	132
18	19.2 - 20.2	E of Lake Padden	252	283
19	20.2 - 21.5	Chuckanut Creek area	111	319

Analysis of the calculated average and peak static release volumes in Table 4A shows, in Table 5A, the effectiveness, or benefits, of the new valves on the drain-down portion of a pipeline release. The new valves are shown to reduce both the average and the peak static release volumes within all but one drainage section as described in Table 3. “Average reduction”, as used in Table 5A, is defined as the average of all the single-point reductions within any given section. “Peak reduction” is defined as the greatest single-point reduction observed among all points (mileposts) within any given drainage section.

The most significant peak static reductions are shown in Sections 15 and 16, which, given a sufficient volume, are predicted to flow into Whatcom Creek. No static reduction is indicated for Section 14. However, the new check valve at MP-16.18 will result in transient spill reduction here by preventing flow reversal during the transient portion of a potential major release, before the RCV’s have fully closed (see Table 5B).

Table 5B - Effectiveness of New Valves On Total Release

Bellingham & Vicinity Mileposts

For “Guillotine” Release (C_v = 80,000)
10-Minutes Transient Release Duration
Existing Valves vs. Existing + New Valves (Case 4 vs. Case 8)

Location			*Reduction with New Valves [bbl]*		
Reference Drainage Section	*Actual Milepost*	*Description*	*Static Reduction*	*+ Transient Reduction*	*= Total Reduction*
10	10.98	South of Kline Rd. crossing	673	844	**1,517**
12	12.34	Stream @ Hannegal Rd. crossing	1,108	519	**1,627**
13	12.96	Squalicum Creek crossing	1,108	649	**1,757**
14	15.01	Alabama St. crossing	0	1,547	**1,547**
15	15.89	Whatcom Creek crossing	0	2,163	**2,163**
16	16.76	New check valve location	2,185	1,934	**4,119**
	18.56	Bellingham area pipeline high point	0	0	**0**
19	20.52	Chuckanut Creek crossing	319	435	**754**
	21.45	High point N of Samish Lake	0	113	**113**

Analysis of the calculated total release volumes for “existing valves” and “existing + new valves” in Table 4B shows, in Table 5B, the total effectiveness, or benefits, of the new valves. The new valves are shown to reduce the potential total-release volumes at all evaluated mileposts, excepting at the local pipeline high-point at MP-18.56. Addition of valves does not offer protection to this high point because no other pipeline points are at higher elevations that could drain to this point; any reductions can be effected only by the spill response time. There are no static release reductions indicated at mileposts 15.01 and 15.89. This is because the existing RCV at MP-16.18 “masks” the static reductions that would be contributed by the check valves installed at MP-16.18 and MP-16.76. These CV’s, however, do contribute to the transient reductions before the existing RCV at MP-16.18 has been fully closed. For a potential pipeline release at the Whatcom Creek location, there is a calculated total reduction of 2,163 bbl, or 46%.

Table 6 - Total Release Volume, 5-Minutes vs. 10-Minutes

Bellingham & Vicinity Mileposts

For “Guillotine” Release ($C_v = 80,000$)
Existing + New Valves
Case 6 vs. Case 8

Location				*Static Release*	*Total Release [bbl]*		*Increase*
Reference Drainage Section	*Actual Milepost*	*Description*	*Elev. [ft]*	*[bbl]*	*Case 6 5-Minutes Release*	*Case 8 10-Minutes Release*	*[%]*
10	10.98	South of Kline Rd. crossing	275	574	1,608	2,221	38.1
12	12.34	Stream @ Hannegal Rd. crossing	185	1,846	3,461	4,564	31.9
13	12.96	Squalicum Creek crossing	145	1,800	3,550	4,507	27.0
14	15.01	Alabama St. crossing	310	1,149	2,317	2,838	22.5
15	15.89	Whatcom Creek crossing	237	1,072	2,007	2,535	26.3
16	16.76	New check valve location	430	0	634	1,055	66.4
	18.56	Bellingham area pipeline high point	870	0	722	1,163	61.1
19	20.52	Chuckanut Creek crossing	365	1,259	2,767	3,581	29.3
	21.45	High point N of Samish Lake	825	152	950	1,504	58.3

Table 6 is a comparison of total release volumes for 5-minutes vs. 10-minutes total response time to fully close the existing and new RCV’s after a potential “guillotine” release begins. For a doubling of the total response time, that is, a 100% increase in the transient release time, the calculated total release increases in the range of 22% to 66%, depending upon the location of the release. The greatest percentage increases generally occur where the static releases are lowest. These percentages apply only to a guillotine-type release in the observed area. That is, for this type of release, a change in response time from 5-minutes to 10-minutes does not result in a proportional change in the total spill. A comparison of these cases is profiled in Appendix-B.

Valve Location Analysis

Pipeline sections are discussed herein with respect to static release volumes. When evaluated for potential spill reductions, the static volume is the component primarily affected by valve location. The transient component is more reliant upon spill response times for pump shutdown and RCV closures. In selecting possible valve locations, consideration is given not only to the size of potential static-release volume, but also to significant reductions impacting sensitive resources.

A remote controlled block valve (RCV) is capable of stopping flow when a leak is located on either its upstream or downstream side. A check valve allows flow in only one direction and so is capable of stopping flow only when the leak is located on its upstream side. The valve type selected for protecting a given location is based on the pipeline elevation profile, the slope direction of the pipeline at that point, and on the area to be protected. The upstream side of a valve is the side that the fluid enters when the pumps are operating, and the downstream side is that which the fluid exits from when the pumps are operating. Check valves are typically located where the fluid is being pumped uphill during normal pipeline operation. Block valves can be beneficially located on up-slopes or down-slopes.

In the text, spreadsheets and charts of this study, two-decimal mileposts are “actual pipe length mileposts,” are calculated in the spreadsheets, and used for pipeline volume calculations. Other milepost designations are from OPL’s field numbering system. These two types of mileposts may differ slightly at any given location. Both types have been identified on the spreadsheets. OPL milepost designations are the only ones that appear on the maps.

In performing the valve location analysis, the Ferndale-Allen pipeline section is broken down into smaller segments. This document addresses only those segments affecting Bellingham. Each segment is essentially self-contained in that a failure within any given segment will result in containment of the static liquid volume within that segment, after closure of existing RCV's and CV's. In some cases, there may be a minor exchange of liquid volumes between neighboring segments. For this evaluation, only the segments that are fully or partially within the defined Bellingham vicinity are discussed. An attempt was made to maximize the length of each segment by utilizing the natural topographical high points, as well as the existing valves, for isolation. All liquid volumes in the following discussions are calculated from potential static (drain-down) releases with the RCV's and CV's closed. The data, profiles and maps located in the Appendices were used to develop this analysis.

Milepost 0.00 to MP-14.63

Location Review with Previously-Existing Valves

This segment of the pipeline is between Ferndale Station on the north end, at 180-ft. elevation, and MP-14.63 at 350-ft. elevation. MP-14.63 is on the north edge of the City of Bellingham. The pipeline passes through the City of Ferndale between OPL mileposts 3 and 5. At OPL milepost 8, the pipeline crosses Silver Creek at a point where it flows northward. Squalicum Creek is crossed at OPL milepost 13, where, about ¾ mile downstream of the crossing, a school and child day care center (CDC) are adjacent to the creek. "Existing" valves in this pipeline segment were RCV's located at Ferndale Station and at MP-6.79 (OPL MP-7). A potential existed for a static release of 3,578 barrels at MP-7.73, the Silver Creek crossing, which could flow in the creek towards sensitive resources in Ferndale. At MP-12.96, Squalicum Creek, the potential static-release volume was 2,908 barrels, and it could enter the City of Bellingham via the creek.

Improvements Made

Two new valves have been installed as follows: a new check valve at MP-8.10 (OPL 8) and a new RCV at MP-11.93 (OPL 12). Only the RCV affects release volumes in the Bellingham vicinity. The check valve reduces potential static drain-down at the adjacent Silver Creek crossings from 3,600-3,700 bbl to 500-600-bbl, a 3,100-bbl (85%)

reduction. At the MP-12.96, the Squalicum Creek crossing, in the Bellingham vicinity, the new RCV decreases potential static drain-down from 2,908 barrels to 1,800 barrels, a 1,108-bbl (62%) reduction. This RCV location also protects the unnamed stream crossing at MP-12.34 and the Hannegan Rd. crossing at MP-12.37.

Milepost 14.63 to MP-18.56

Location Review with Previously-Existing Valves

This segment extends southward, from MP-14.63 at an elevation of 350-ft., to an elevation of 870-ft. at the Ferndale-Allen pipeline section high-point. The City of Bellingham is located between OPL mileposts 14 and 17, and has the greatest abundance of sensitive resources. Whatcom Creek, the location of the 1999 spill, is located at OPL milepost 16. The only “existing” valve was an RCV located at MP-16.18 (OPL 16). Potential static release within the City of Bellingham was 0–1,072 barrels upstream (north) of the RCV and 1,898-2,864 barrels downstream of the RCV.

Improvements Made

Two new valves have been installed as follows: a new check valve at MP-16.18 and a new check valve at MP-16.76 (OPL 17).

- The check valve at MP-16.18, in accordance with the “Pipeline Safety Immediate Action Plan,” backs up the existing RCV at the same milepost. It’s purpose is to reduce the response time required to isolate this segment, as well as to serve as a backup in case the RCV fails to close. There is no calculated reduction in potential static drain-down for this valve. However, this valve will reduce the transient release volume resulting from a major upstream leak because it will close automatically upon flow reversal rather than waiting for operator intervention after leak detection.

- The addition of a new check valve at MP-16.76 reduces potential static drain-down by 2,185-bbl at all points between this CV and the valves at MP-16.18. The peak potential static-release, which occurs at MP-16.20, is reduced from 2,864 barrels to

679 barrels (76% reduction). At the upstream end of this CV, there is a reduction from 2,185 barrels to zero barrels (100% reduction). This CV reduces the potential volume that could enter Whatcom Creek via the stream path adjacent and parallel to the pipeline in this segment. It also protects the area near the middle school located up-slope from the valves at MP-16.18. In the densely populated area within the Bellingham City limits, between MP-13.80 and MP-17.00, the average potential static drain-down volume is reduced from 1,150 barrels to 801 barrels, a 349-bbl (30%) reduction.

Milepost 18.56 to MP-21.45

Location Review with Previously-Existing Valves

This segment extends southward, from MP-18.56, the pipeline section high-point of 870-ft. elevation, to an elevation of 825-ft. at MP-21.45. In this segment, the pipeline dips to a low elevation of 350-ft. at MP-20.36, the Chuckanut Creek crossing. The pipeline crosses Interstate Highway I-5 at MP-20.22 and Chuckanut Creek at MP-20.52. The peak potential static-release in this segment was 1,950 barrels at MP-20.36. This segment is lightly populated adjacent to the pipeline ROW. There were no “existing” valves in this segment.

Improvements Made

A new CV has been installed at MP-20.60. It reduces potential static release at the I-5 crossing from 1,950 barrels to 1,632 barrels, a 319-bbl (16%) reduction. At MP-20.52, Chuckanut Creek, the reduction is from 1,578 barrels to 1,259 barrels, a 319-bbl (20%) reduction. The peak potential static-release occurring at MP-20.36 is reduced from 1,950 barrels to 1,632 barrels, a 319-bbl (16%) reduction.

6.0 SENSITIVE RESOURCES

For the purpose of this evaluation, Sensitive Resources were identified using input from the following sources:

- Yahoo! Internet Yellow Pages, dated Oct. 5, 1999;
- Washington Education Directory, Office of State Superintendent of Public Instruction, Copyright 1999-2000;
- Major buildings and landmarks from the Olympic Pipe Line Company Geographic Response Plan (GRP), dated Jan. 1996;
- U S WEST Dex, White & Yellow Pages, Bellingham and Whatcom County, Wash., 1999 – Jan. 2000;
- Totem Atlas of Island, Skagit, Whatcom, and San Juan Counties, Copyright 1999;
- Thomas Guide, Pacific Northwest, Copyright 1998;
- USGS Topographic Quadrangle Maps, 1:24,000 Scale

The resulting data, which was obtained from these sources, may be found on the topographical maps in Appendix-C, under the heading “Pipeline Alignment and Predicted Drainage Paths”. The sensitive resources include residential areas, population and business centers, schools, hospitals, rivers, creeks, streams, lakes, parks and wildlife preserves. All sensitive resources may not have been identified, necessarily, but an attempt was made to obtain a sufficient sampling to show points of concentration. Since most residential areas have grown since the USGS topographical maps were originally prepared, current Thomas maps were used to determine these areas.

Evaluation of all potential spill impacts has been made by comparing the release volume profiles in Appendix-B with the drainage maps in Appendix-C. Areas of relatively high release volumes were identified and then compared with the abundance or concentration of sensitive resources identified on the maps in the same locations, particularly those within the potential drainage paths. Valve recommendations were then made where significant spill volume reductions could be obtained.

Sensitive resources, road crossings, etc. identified on Appendix-A spreadsheets were taken from pipeline alignment sheets, the USGS topographical maps, and other sources which may no longer be current. No attempt has been made to correct for possible name changes that may have occurred since that time.

7.0 HEAVIER THAN AIR VAPOR ANALYSIS[2]

General

The pipeline transports diesel, commercial jet fuel, and gasoline. In order for a product to produce a flammable vapor cloud when released into the atmosphere, the product must be physically capable of producing flammable vapors when exposed to atmospheric conditions (temperature and wind) and ground temperature. Materials that have a flash point above 100°F are classified as combustible, but not flammable, by the National Fire Protection Association, Inc. (NFPA) 30 – Flammable and Combustible Liquids Code. By definition, a combustible material cannot produce enough vapors to create a flammable gas cloud unless heated. Flash point is defined as the lowest temperature at which a material gives off sufficient vapor to form an ignitable vapor-air mixture near the surface of the material (to flash into a momentary flame when ignited). Diesel fuel and commercial jet fuel have flash points greater than 100°F and thus, are not capable of producing a flammable vapor cloud unless heated. Gasoline has a flash point of well below zero degrees F and is thus capable of producing a flammable vapor cloud that can drift with the wind, and become ignited. Gasoline vapors are heavier than air, tending to remain closer to the ground for a longer time before they disperse, as opposed to vapors that are lighter than air. The remainder of this section addresses releases of gasoline.

There are many factors affecting the amount of vapor that is produced from a spill and the distance that the vapor cloud can travel before its concentration falls below its lower flammability limit (LFL). The LFL is the maximum vapor concentration at which the vapor cloud could be ignited; LFL for gasoline is 1.4%. First, a release must occur before flammable vapors can be produced. Once a release occurs, evaporation begins and flammable vapors are produced. The rate of evaporation is a function of the surface area from which evaporation may occur, the temperature of the gasoline, the temperature

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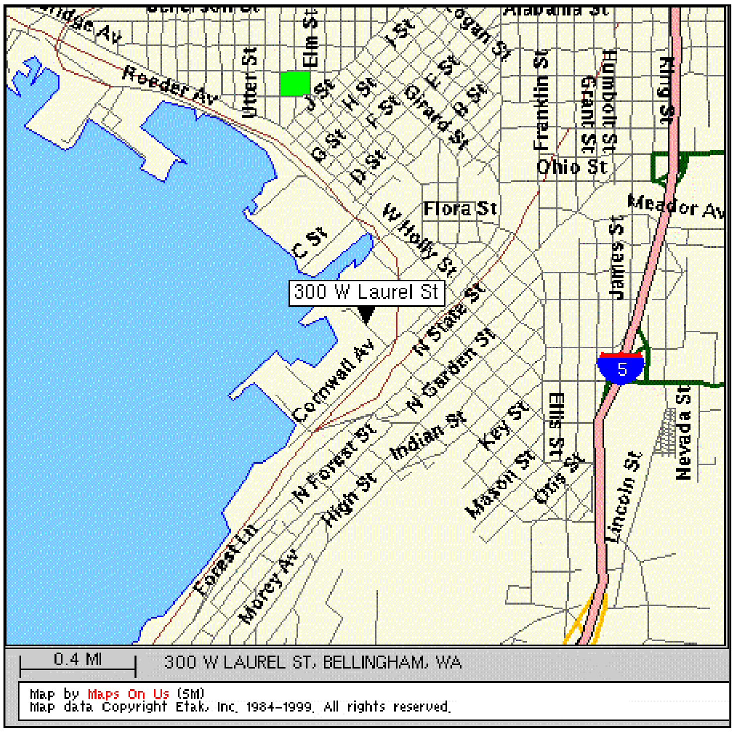
[2] Heavier than air vapor analysis was completed at the request of the City of Bellingham.

of the atmosphere and ground, and the wind speed. The area formed by the release is discussed here while the other factors are discussed later under Vapor Cloud Modeling.

If a release should occur, the gasoline would begin to flow in accordance with the drainage footprint. Depending on the surface type, some gasoline could soak into the ground. Gasoline remaining on the surface begins to evaporate immediately. The larger the surface area formed by the release, the greater the evaporation that takes place. It is difficult to determine the size of the pool formed by a release at a particular point, and thus the surface area, because of the variability of the terrain. A small amount released onto a flat paved area that is contained could result in a greater amount of flammable vapors than a large release into a narrow stream that results in a relatively small surface area. Furthermore, flammable vapors produced by a relatively uniform shape, such as a circular or square puddle, tend to stay together and travel farther before dispersing to levels below the LFL. Vapors produced by long narrow pools formed by streams and narrow canyons would have the opposite effect. Because of this variability, a variety of pool sizes have been selected to be representative of the cases that could occur. These pool sizes vary from 1,000 square feet (ft.^{2}) to 100,000 square feet. A conservatively evaluated spill size of approximately 5,000 bbl (Section 3, static plus transient components) that spreads uniformly to 100,000 ft.^{2} would be a little greater than 3 inches deep. Due to terrain irregularities and the fact that some gasoline would most likely soak into the ground, it is highly unlikely that such a release would form a relatively circular pool with an area greater than 100,000 ft.^{2}. Thus, the evaluated 100,000 ft.^{2} pool is considered as a very conservative scenario.

Climatology

In case of an accidental spill from the pipeline, vapors from the spilled product would travel in the direction of the wind. Wind speed and temperature are factors in determining the product evaporation rate. In order to examine wind patterns in the area, a series of wind frequency distributions for Bellingham, Washington was developed. Resulting wind roses are shown in Figures 7-1 through 7-5. Wind frequencies are shown for each of sixteen 22.5° sectors (i.e., NNE, NE, ENE, etc.). The length of each is proportional to the frequency of winds coming from that direction. Winds represented in the figures were recorded hourly for the entire year of 1998 at a Georgia Pacific[3] site (see location map below) in Bellingham. While patterns will vary somewhat year to year, the overall features of these wind roses are expected to reflect general climatological patterns regarding wind speed and direction.



Due to variations in topography along the route, which influences wind direction and speed, these winds are not representative of all conditions everywhere along the route. However, they are expected to be reasonably representative of winds along the portion of the pipeline from Ferndale Station to Bellingham, where terrain is less complex. They also give at least an indication of potential wind patterns along the remaining portion north of Allen Station.

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[3] Georgia Pacific Corp., 300 West Laurel Street, Bellingham, Washington 98225-5540

Figure 7-1 shows a wind rose for the full year of 1998. There is a clear scarcity of winds coming from the northwest quadrant, with the greatest amount coming from the southwest quadrant. Wind speeds were usually less than 6 knots (7 mph). The average wind speed for the year was 4.3 mph. Note that since the wind rose shows directions from which the wind is blowing, vapors would be carried in the opposite directions. For example, if the winds were from the west, vapors would be carried towards the east.

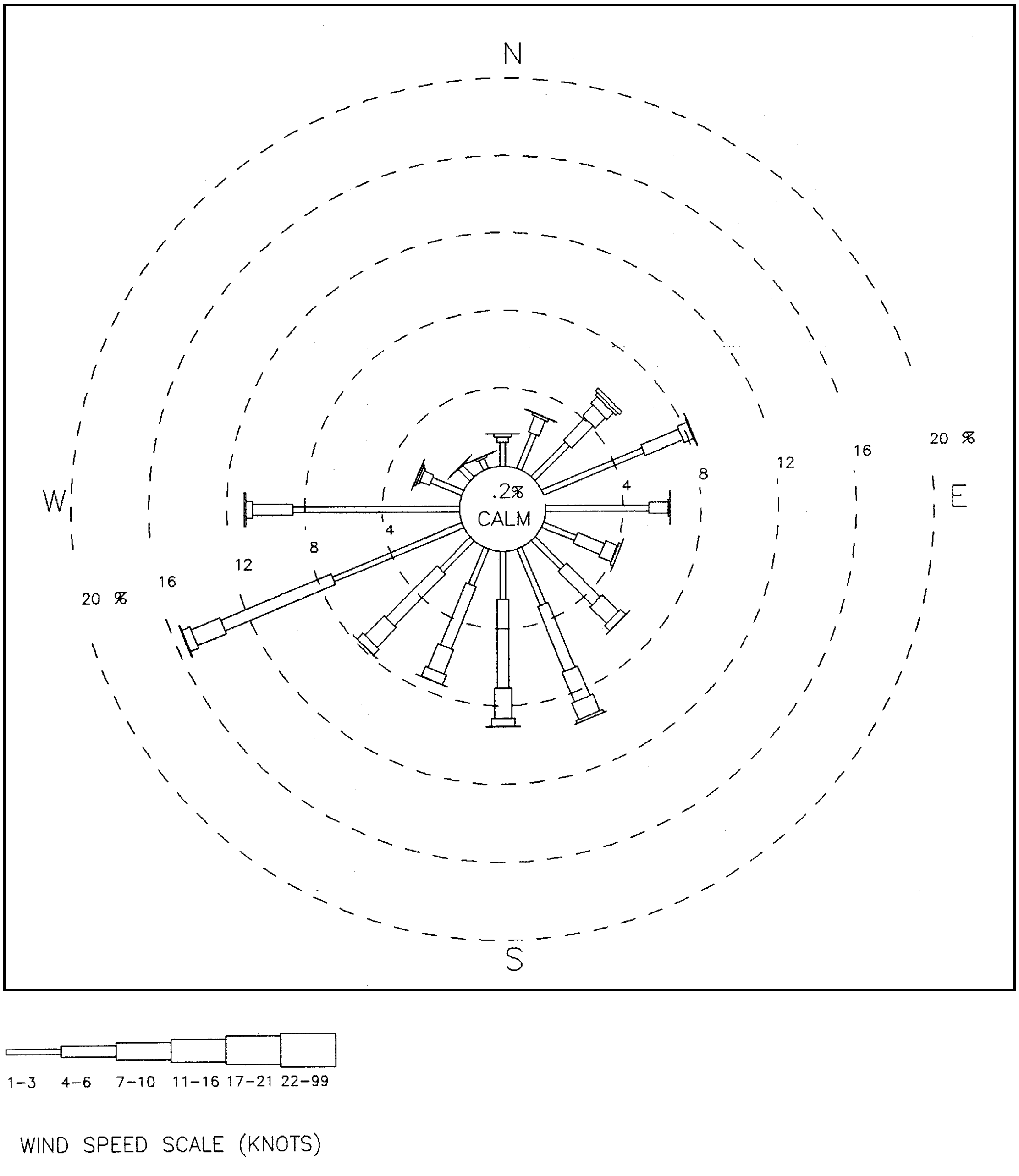

Figure 7-1 - Annual Wind Rose
Bellingham, Washington - 1998

Figures 7-2 and 7-3 show wind roses for summer and winter 1998, respectively. Summer is defined as June, July, and August. Winter is defined as December, January, and February. Transitional spring and fall months were skipped in favor of the extreme periods of the seasonal cycle. Summer winds were overwhelmingly from the southwest quadrant with an average speed of 4.0 mph. In contrast, winter winds came from the southeast and northeast quadrants with a relatively small frequency from the summer’s favored southwest quadrant. The average wind speed in winter was 6.2 mph, about 50% greater than in the summer months.

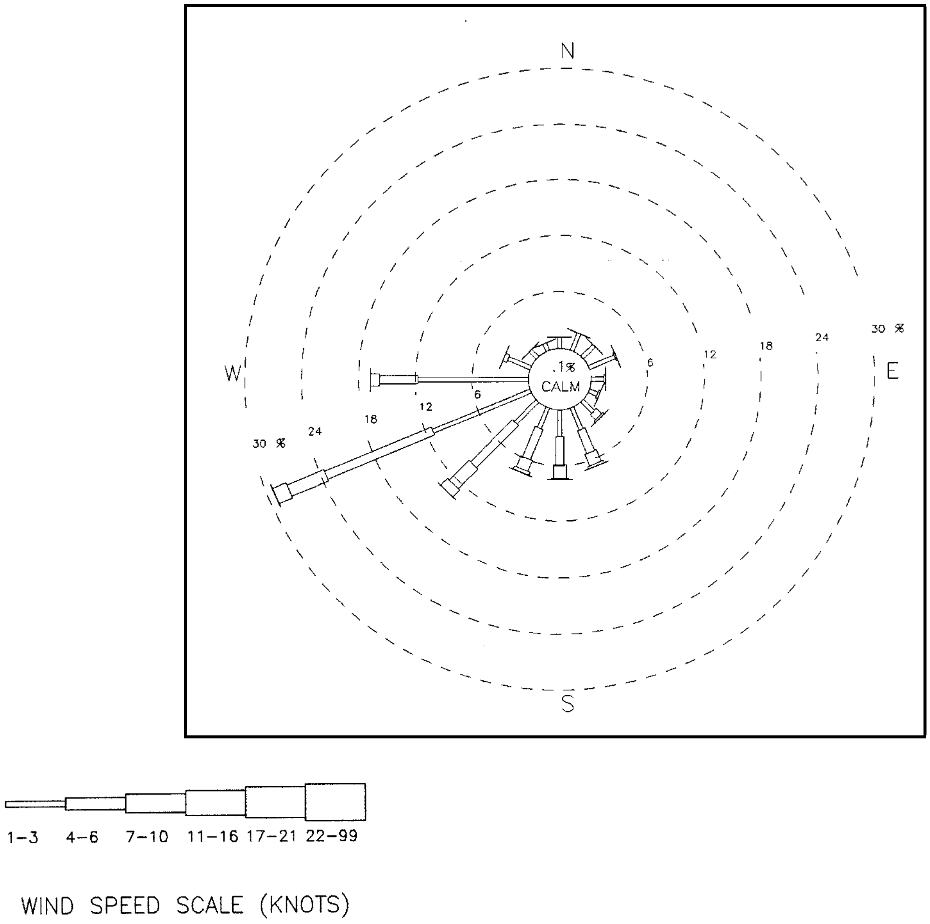

Figure 7-2 - Summer Wind Rose
Bellingham, Washington – 1998

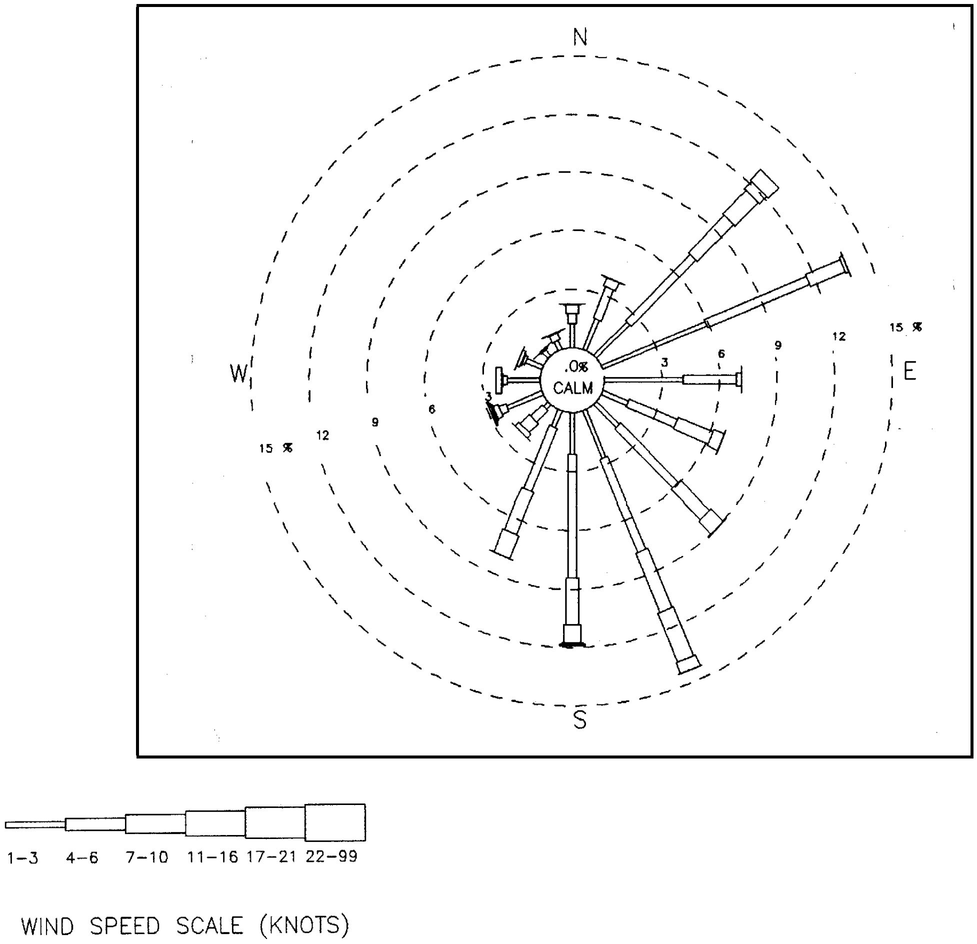

Figure 7-3 - Winter Wind Rose
Bellingham, Washington - 1998

A parsing of wind roses into day and night is shown in Figures 7-4 and 7-5, respectively. Day is defined as 10 AM to 4 PM and night is defined as 10 PM to 4 AM. Transitional morning and evening periods were skipped in favor of the extreme periods of the daily cycle. Interestingly, the daytime wind rose strongly resembles the summer pattern and the nighttime wind rose strongly resembles the winter pattern. To an extent, these similarities may indicate the effect of warmer and cooler temperatures on wind patterns. The average daytime wind speed is 5.6 mph, about 50 percent faster than the average nighttime speed of 3.6 mph.

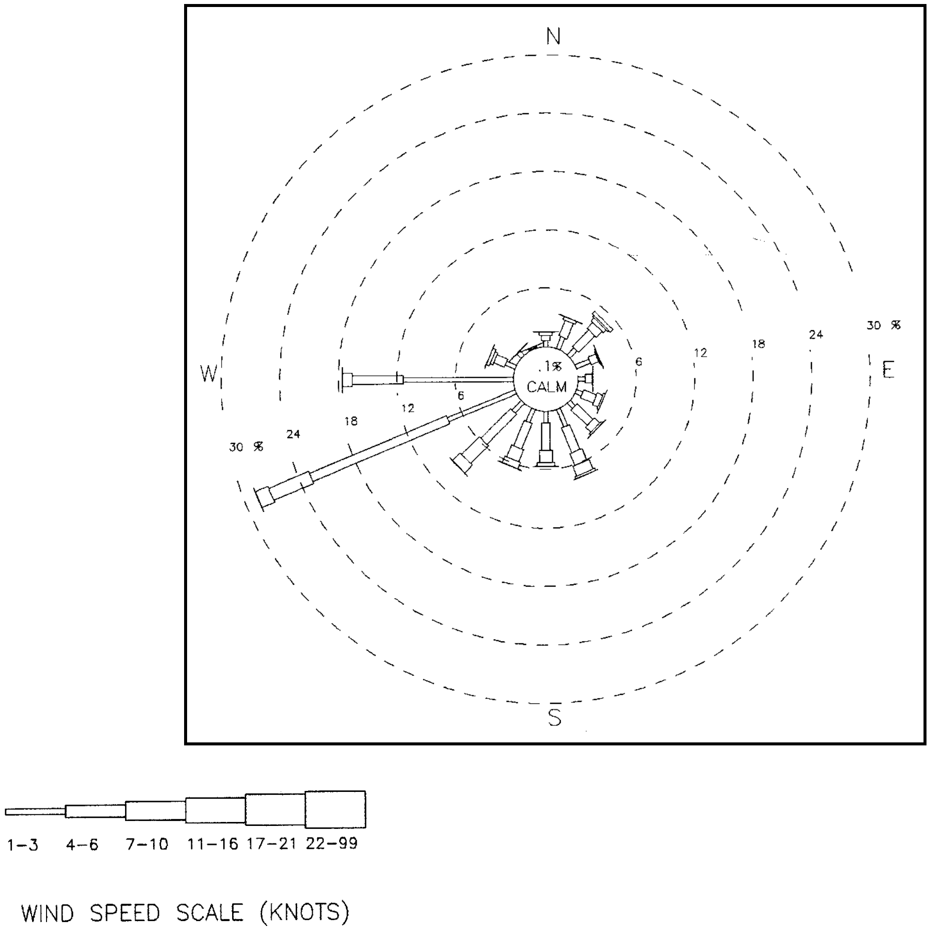

Figure 7-4 - Day Wind Rose
Bellingham, Washington - 1998

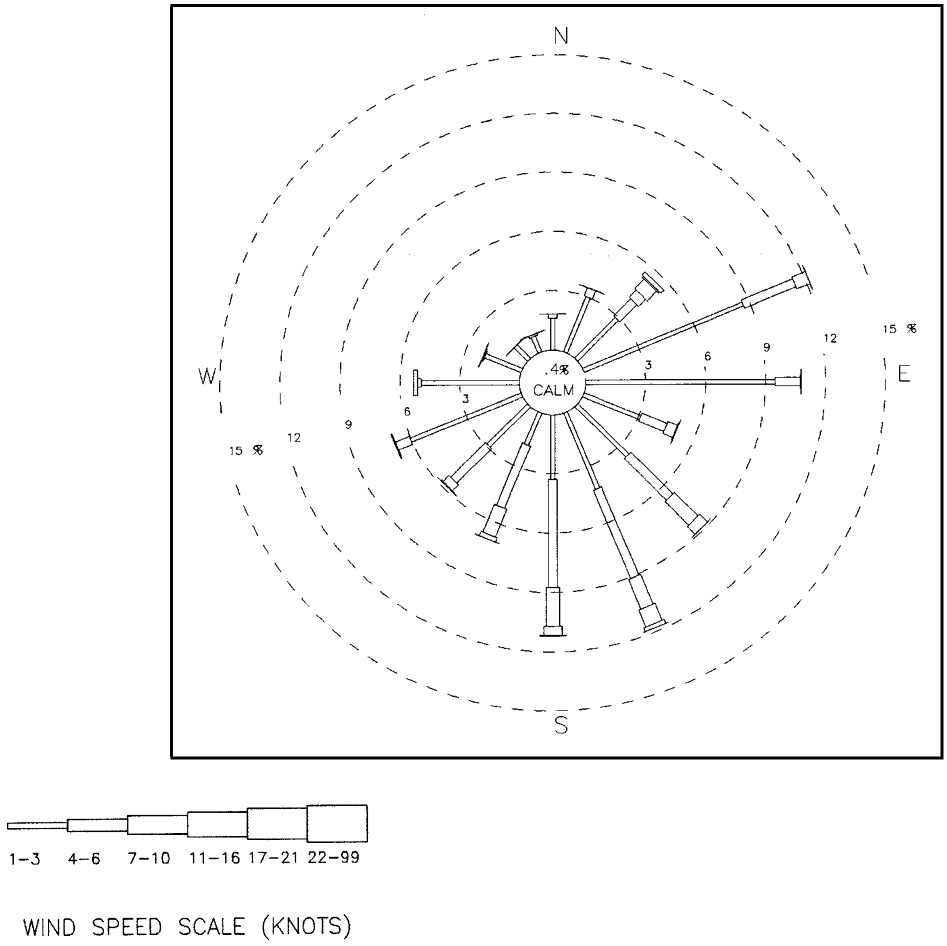

Figure 7-5 - Night Wind Rose
Bellingham, Washington - 1998

Bellingham has a mild climate with relatively cool summers and moderate winters. Table 7 is a summary of monthly temperatures in Bellingham, including average daily maximum and minimum temperatures, and daily averages. The coldest month is January, with an average daily temperature of 37°F, and the warmest months are July and August, with an average daily temperature of 63°F. Average daily minimums range from 32°F in January to 54°F in July and August. Average daily maximums range from 42°F in January to 71°F in July and August. Daily minimums generally occur in the hour or two before sunrise while daily maximums occur in the mid-afternoon.

Table 7 - City of Bellingham Average Monthly Temperatures

Month	***Average Temperatures [°F]***		
	Daily Minimum	***Daily Maximum***	***Daily Average***
January	32	42	37
February	34	48	41
March	37	51	44
April	41	56	49
May	45	63	54
June	51	68	60
July	54	71	63
August	54	71	63
September	48	66	57
October	42	58	50
November	37	49	43
December	33	44	39
Annual	**42**	**57**	**50**

Source: The NOAA-CIRES Climate Diagnostics Center
(http:/www/cdc/noaa.gov)

Pipeline Product Characteristics

As discussed previously, the OPL pipeline system is used to transport various petroleum products to market. These products include gasoline, diesel, and commercial jet fuel. A variety of gasoline types is transported. For purposes of this analysis, gasoline can be divided into two grades: unleaded regular (ULR), and unleaded intermediate (ULI). As the characteristics of the product will affect the hazards presented in case of a major spill, those characteristics are presented in Table 8.

Table 8 - Pipeline Product Chemical Characteristics

Product Characteristic	*ULR Gasoline*	*ULI Gasoline*	*Diesel*	*Commercial Jet Fuel*
Molecular Wt (MW)	~91	~91	Varies	Varies
Lower Flammability Limit (LFL) [%]	1.4	1.4	0.5	0.5
Boiling Pt [°F]	90	90	650	515
Density [lb/gal]	5.9	5.9	7.3	6.8
Vapor Pressure [mm Hg @ 100°F]	362 - 403	465 - 775	0.07 - 0.3	<7
Temperature in Pipeline [°F]	50	50	50	50

These characteristics were determined from Material Safety Data Sheets (MSDS) from the shippers and other sources. The product temperature in the pipeline is the annual average ambient temperature, which is a good approximation of the temperature below ground. Since the pipeline is not insulated, the product temperature would quickly come into equilibrium with the ground temperature.

While the characteristics for any given run of product may differ somewhat from those indicated here, these give a reasonable description of the products transported by the Olympic Pipe Line. In the case of vapor pressure, where a range is indicated, the upper end of the range would result in the faster evaporation to the air of spilled product. It should be noted that gasoline vapor pressure in Summer would be no more than about 465 mmHg (9 psia at 100°F) due to federal restrictions that apply in the summer months to reduce air emissions.

Vapor Cloud Modeling

Vapor cloud modeling involves estimation of vapor emissions to the air and the subsequent dispersion of those vapors. Model results can be used to estimate the extent of a hazard footprint associated with the spill. In the case of a petroleum product spill, the hazard area is defined as the downwind distance within which the cloud remains flammable. That is, the distance within which the cloud could be ignited in the presence of a spark or flame. Many variables are involved in determining the size of a hazard footprint. These include, in a broad sense, the amount spilled, the vapor emission rate and flammability limits, the dispersion potential of the surrounding atmosphere, and the factors affecting each of these parameters.

The potential average and peak static liquid release-volumes are shown in Tables 4A and 4B. As discussed in Section 5.0, the size (volume) of an accidental spill depends upon a number of factors, including size of the leak, leak location, response time, block valve location, local geography, and others.

The formation of vapors, via evaporation of exposed product after a spill, is dependent upon additional factors. These include product vapor pressure, product boiling point, product molecular weight, product temperature, air temperature, wind speed, and surface area of the exposed pool. The pool surface area is, in turn, partially a function of the spill size. As discussed previously, the geophysical characteristics of the spill vicinity are also very important in determining the pool surface area. In particular, these characteristics include the topography, ground porosity, and ground permeability. As shown in the Section 5.0 Drainage Analysis, spills at most locations along the pipeline would not pool. Rather, they would follow the drainage paths to points of lower elevations.

Given the number of variables that go into determining the vapor emission rate of a spill, it is difficult to make an exact estimate for a given spill. Therefore, the analysis presented is intentionally conservative. The rate of vapor emissions is dependent upon the surface area. The duration of those emissions is more dependent upon the volume in the pool. For example, a pool with an area of 10,000 $ft.^2$ might emit vapors at a rate of 500 lb./min., under certain conditions. A pool with 5,000 lb. of product would then take 10 minutes to evaporate if the rate remained constant. If the pool contained 10,000 lb., but the same surface area, it would still emit at the 500-lb./min. rate but would take twice as long to evaporate. Spill response activities could potentially reduce the amount evaporated by a significant amount.

For this analysis, a range of spill surface areas was assumed, from 1,000 $ft.^2$ to 100,000 square feet. Primarily because of much higher vapor pressures, gasoline was found to have much higher vapor emission potential than diesel or commercial jet fuel. The ULI grade has a significantly greater vapor pressure than the ULR grade. As a conservative scenario, the modeling analysis assumes a spill of ULI gasoline and the upper end of the vapor pressure range was used. This assumption will result in the highest calculated emission rate and the largest hazard footprint for a spill of any of the transported products.

Spill emission rates and hazard footprints were calculated with the widely used computer program titled, "Automated Resource for Chemical Hazard Incident Evaluation" (ARCHIE). ARCHIE was developed for the Federal Emergency Management Agency (FEMA), the U.S. Department of Transportation (DOT), and the U.S. Environmental

Protection Agency (EPA). ARCHIE provides emergency preparedness personnel with several integrated estimation methods to be used in assessing the vapor emission rate, and the vapor dispersion, fire and explosion impacts associated with episodic discharges of hazardous materials to the terrestrial environment. The program is described in the Handbook of Chemical Hazard Analysis Procedures[4]. The hazard footprint was taken as the distance from the source where the concentration of the vapor cloud falls below the lower flammability limit (LFL).

Emission rates were calculated, using ARCHIE, for each of five possible spill areas and assuming that the spilled product is ULI grade gasoline with a vapor pressure of 775 mm Hg at 100°F. Using this information and the boiling point temperature, ARCHIE is able to calculate the vapor pressure at the assumed ambient temperature. The ambient temperature was assumed for all cases to be 85°F as a conservative maximum value. For a given spill scenario, a higher ambient temperature results in a higher emission rate. As discussed previously, the highest average temperature in the study area is 71°F in July and August. Temperatures above 85°F are unusual in the study area, so this temperature was taken as a reasonable upper value for all gasoline vapor-emission scenarios. The fact that the assumed winter-season gasoline would not be present during the summer months (those months most likely to experience an 85°F day) increases the conservative nature of the analysis. This is because the winter-season vapor pressure of gasoline is higher than the summer-season vapor pressure.

Another set of variables considered in calculating emission rates includes atmospheric stability and wind speed. Atmospheric stability is a measure of mixing potential and, therefore, dispersion of the vapors. Wind speed affects both the emission calculation and dispersion, a higher speed leading to both a higher emission rate and greater dispersion. Typical and extreme-case meteorological conditions were used. The typical case used was neutral atmospheric stability (Class D), generally the median condition, with a wind speed of 4.5 mph, approximately the average annual speed in the study area. The

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[4] FEMA, et al, 1989

extreme-case scenario used a very stable atmosphere (Class F) and a minimum wind speed of 2.2 mph. This is equivalent to 1 meter per second, which is the lowest wind speed generally recommended for dispersion models by government oversight agencies in their modeling protocols. The use of a higher wind speed for the extreme-case meteorological scenario would result in higher emissions than the speed assumed. However, the higher speed would also result in greater downwind dispersion or dilution of emissions. The combined effect of wind speed on emission rate and dispersion is that a lower wind speed leads to a larger hazard footprint. Thus, the lower wind speed was assumed as a most conservative assumption.

Table 9 shows the vapor emission rates calculated with ARCHIE for the various spill areas and meteorological conditions examined. It is easily seen that the emission rate is directly proportional to the spill area by comparing emission rates for 1,000, 10,000, and 100,000 square feet. The effect of the wind speed on emission rate can also be seen by comparing results for the two columns. The emission rate is not affected directly by the stability class. However, both stability and wind speed are indicated because these combinations were used for the dispersion calculations corresponding to each scenario.

Table 9 - Gasoline Vapor Cloud Vapor Emission Rates [lb./min.]

Spill Area [square feet]	*Stability Class / Wind Speed*	
	D/4.5 mph (typical)	*F/2.2 mph (conservative)*
1,000	140	80
5,000	700	410
10,000	1,400	820
50,000	7,020	4,110
100,000	14,050	8,210

Table 10 shows the calculated hazard footprint distances (distance to the lower flammability limit of 1.4%) for the various scenarios. Depending on the scenario, calculated footprint distances range from 104 ft. to 1,565 ft. (approximately three-tenths of a mile). The combined effect of stability and wind speed causes the extreme-case (conservative) meteorological scenario to predict distances 26 percent greater than the typical scenario for a given spill size.

Table 10 - Gasoline Vapor Cloud Hazard Footprint Distances [ft.]

Spill Area [square feet]	***Stability Class / Wind Speed***	
	D/4.5 mph (typical)	***F/2.2 mph (conservative)***
1,000	100	130
5,000	250	310
10,000	360	450
50,000	850	1,080
100,000	1,240	1,560

The potential for increased evaporation due to a high pressure release of gasoline from a ruptured pipeline, i.e., a failure that forced a liquid stream into the air, was investigated as part of the study. While the model did not explicitly deal with this type of release, the conservative scenario that was modeled was more than adequate to represent the case in which a pipeline rupture spews a stream of gasoline into the air.

The logic employed acknowledged that the initial release rate of a pipeline that ruptures due to over-pressurization could exceed the maximum throughput (pumping) rate. If fluid friction in the pipeline is totally ignored, the calculated initial release-rate could be as high as 118,000 pounds per minute (27,400 barrels per hour). Consequently, 12% of the gasoline must evaporate immediately or be suspended in the air, in order to equate to our conservative scenario. The initial release rate would drop quite rapidly. If the pumps continue to run, the release rate would decrease to the pumping rate. Once the pumps are shut down, the release rate would be a function of the head pressure in the pipeline. Thus, our conservative scenario, which results in an evaporation rate of 14,000 pounds per hour, is more than adequate to represent the case of gasoline spewing into the air.

Vapor Cloud Modeling Supplement

The previous vapor cloud modeling discussion appeared in the original issue of this evaluation, dated October 27, 1999. The following serves to further clarify the conservative nature of the original analysis:

The original issue of this evaluation contained an analysis of the potential size of vapor cloud that could be formed by a release of gasoline from the Olympic Pipeline. This analysis used extremely conservative assumptions which, by nature, lead to a highly probable over-prediction of the size of the flammable vapor cloud. The conservative assumptions included the following:

- The vapor pressure of the gasoline was assumed at 775 mmHg, which is the maximum for ULI gasoline at 100ºF. The maximum vapor pressure for ULR gasoline is 403 mmHg at 100ºF, which would result in significantly less evaporation. The federally mandated maximum vapor pressure for summer gasoline is 465 mmHg at 100ºF. Assuming a vapor pressure of 465 mmHg results in about 80% of the evaporation rate as compared to the 775 mmHg case. This in turn results in a smaller flammable gas cloud.

- The analysis assumed that the evaporation rate of the pool of gasoline continued at the initial rate, which was calculated based on the initial assumed vapor pressure of the gasoline. In reality, the lighter ends in the gasoline would evaporate first, thereby lowering the vapor pressure and decreasing the evaporation rate over time.

- The ARCHIE model was used to estimate both the evaporation rate of the gasoline pool and the extent of the flammable gas cloud. ARCHIE is a conservative model developed for use by planning and emergency response agencies, e.g. FEMA, EPA, and local fire departments. It assists in estimating areas that may be exposed to hazards, and which may need to be evacuated, in case of an accident. As such, the model has purposely been designed to err on the conservative side. For example: The evaporation rate of a 100,000 sq. ft. pool calculated by the Hazard Footprint Calculation Program (HFCP), is about 59% of that calculated by ARCHIE. HFCP is utilized by the Ports of Los Angeles and Long Beach, CA.

Since the original analysis, the City of Bellingham has expressed concerns about the potential for gasoline vapors and droplets being produced from a jet stream release. Modeling showed that the conservatively estimated initial release rate could be as high as 27,400 bph (118,000 pounds per minute). Twelve percent of the released material would have to immediately flash to vapor to result in a vapor production rate equal to the 100,000 sq. ft. evaporating pool scenario. The following presents the results of some additional analysis involving a jet release of gasoline.

First, the potential release rate from the pipeline was examined. As determined by the Stoner Associates, Inc. hydraulic model, the maximum release rate of 27,400 bph at milepost 16.76 lasts for only a few seconds. The release rate then drops approximately to the pumped throughput of the pipeline (9,272 bph) and continues at that rate until the pumps are shut down. The pipeline then drains down at a lower rate due to gravity.

As a most conservative case, it was assumed that the entire 27,400 bph immediately turned to vapor, which can clearly be considered an acutely conservative exaggeration. A review of models determined that the Dense Gas Dispersion Model (DEGADIS) could model a jet release of gas. DEGADIS cannot directly model a jet release of liquid. DEGADIS is listed in the U.S. EPA's Guideline on Air Quality Models (40 CFR Part 51, Appendix W). Documentation of the DEGADIS model includes an evaluation of the Jet-Plume Module in which model predictions were compared to measurements in a wind tunnel. Model predictions were found to compare well with measured concentrations.

As the DEGADIS model is configured, any jet release is assumed vertical. This does not allow for direct examination of a plume released horizontal to the ground. However, the output of the model provides the calculated gas concentration within the plume as it rises from the momentum of its release. Without the frictional effects of the ground, plume dispersion of a vertical jet should be less than that of a horizontal jet. Thus, reliance on the vertical jet concentrations could be seen as an upper limit on the concentrations from a corresponding horizontal jet.

The following atmospheric conditions were assumed to occur during the hypothetical pipeline failure:

Wind speed -	1.0 m/sec at 1.0 m above ground (2.2 mph)
Atmospheric stability -	F (very stable)
Ambient temperature -	293°K (59°F)
Atmospheric pressure -	1.0 atm (14.7 psia)
Relative humidity -	50%

DEGADIS begins by modeling the release as a jet-plume. Because of the velocity and turbulence of the jet release, the gas rapidly mixes with the air. Once the gas stops behaving as a jet, the model treats the gas cloud as Gaussian. It was assumed that the gasoline was released from a 16-inch diameter hole (the diameter of the pipeline).

DEGADIS determined that the release of 27,400 bph of gasoline, if represented as 100 percent vapors, would fall below the 1.4 - percent lower-flammability limit of gasoline at a distance of 370 feet. This is substantially less than the reported 1,565-ft. size of the flammable-vapor-cloud hazard footprint for the 100,000 $ft.^2$ evaporating pool. While this case represents an upper boundary for a jet release, it is unrealistic to assume that 100 percent of the released gasoline would immediately flash to vapor.

A second case was examined in which it was assumed that half the gasoline would flash to vapor. In this case, the gas cloud falls below the LFL at a distance of approximately 306 feet.

A third case was examined in which the vapor release rate was assumed at 5,000 barrels per hour. This case is representative of a jet release from a smaller hole of around one to three inches in diameter. Again, assuming all the gasoline immediately vaporizes, DEGADIS calculated a distance to the LFL of approximately 74 feet.

It can be seen by the above analysis that the size of the flammable gas cloud from a jet release is much less than the size of the cloud from a large, evaporating pool. The main reason that a jet release does not go as far as an evaporating pool release is that the force of the gas exiting the pipeline creates extreme turbulence, which in turn causes the jet to rapidly entrain air. This reduces the concentration of the gas in the cloud sooner. The vaporization from a jet release would most likely result in a flammable gas hazard footprint smaller then that from an evaporating pool for two additional reasons. First, whatever amount of gasoline that vaporizes is not available to go into the pool which, in turn, could result in a smaller pool. Second, vaporization of the gasoline would result in a significant cooling effect in the cloud that would cool the remaining liquid, which then falls to the ground to form the pool. This cooling effect would decrease the evaporation rate of the pool.

8.0 SUMMARY

General

This evaluation covers those sections of the pipeline in Bellingham and vicinity that could gravity drain to points within the City of Bellingham, were a leak to occur, and the control of those potential releases. It includes the area between the following pipeline crossings: approximately ¼-mile N of Kline Road, at pipeline milepost MP-10.51, to approximately ½-mile N of Roy Road, at pipeline MP-21.45.

With milepost and elevation information from the pipeline alignment sheets, a pipeline elevation profile has been developed and point-to-point pipeline-volume spreadsheets have been prepared for the 16” Ferndale to Allen pipeline, including Bellingham and vicinity. Review of the elevation profile assisted in the development of spreadsheet formulas for potential pipeline release volumes. Applicable volumes that could gravity-drain from a leak at each milepost, after the pipeline valves have been closed, were then calculated. These are called “potential static-release volumes”. These volumes were initially calculated for the “No Valves” case. Then, volumes were calculated for closure of the existing remote control valves (RCV) and check valves (CV). Review of the release volume profile for closure of existing valves enables the evaluator to determine areas with relatively high potential releases. “Existing” valves were present at the time of the 1999 Bellingham area pipeline failure. Static release volumes are used to evaluate valve effectiveness because valve locations primarily affect these volumes, which release after the valves have fully closed.

United States Geological Survey topographical maps were prepared with spill drainage footprints for use in determining potentially affected areas. Sensitive resources were identified on the maps along the pipeline right-of-way, near and within the City of Bellingham. These were compared with potential spill-drainage paths to determine which sensitive resources may be directly affected by a pipeline release. The drain-down volume released within any section, after closure of all existing RCV’s and CV’s, was then compared with the locations and abundance of sensitive resources within that same section. New valves were then proposed where significant improvements could be obtained, and release volumes were re-calculated to determine the level of improvement with the new valves. There are no existing hand-operated valves (HOV) in this area to be considered for conversion to remote operation.

As the distance between a potential leak site and a valve increases, the potential static volume that may be released also increases. Therefore, the further a valve is from a leak, the less effective the valve is in reducing the size of the release. In general, check valves are located at or prior to upward sloping areas and block valves are located at or following downward sloping areas to reduce product release to the “valley” areas. The deeper valley areas have the potential for the greatest release volumes. However, placing a valve closer to the bottom of one of these valleys reduces the length of pipeline that is protected. Hence, the selected valve location may be a balance between spill reduction size and size of the area protected.

Critical Valves

There are four “critical” valve milepost (MP) locations. In accordance with the “Pipeline Safety Immediate Action Plan,” critical valves are defined as those affecting potential release volumes with drainage paths through the City of Bellingham. These locations are MP-11.93, MP-16.18, MP-16.76, and MP-20.60. The two RCV’s, located at MP-11.93 and MP-16.18, are operated through the supervisory control and data acquisition (SCADA) system at the Olympic Pipe Line Company (OPL) Renton control center. In case of a pipeline release, the pumps will be shut down and these valves will be remotely actuated to close. The check valves will close automatically upon a sufficient upstream release or upon pipeline shutdown. None of these locations has an HOV.

In accordance with the “Pipeline Safety Immediate Action Plan,” a check valve was installed with the existing RCV at MP-16.18. The check valve will more rapidly isolate the pipeline segment than the RCV alone because of its quick automatic closure upon flow reversal. It will serve to reduce the potential liquid release back flowing from the downstream (up-slope) portion of the pipeline, past the RCV, while the leak is being detected and the RCV is being closed.

The new valve location at MP-20.60 has a CV only, which will close automatically upon flow reversal. Due to its simple, automatic, mechanical operation, a backup to this valve is not warranted.

In accordance with the “Pipeline Safety Immediate Action Plan,” both of the RCV’s have been retrofitted with additional backup controls. They are anti-surge pressure switches, designed to prevent the pipeline pressure from rising to an excessive level due to valve closure. Surge control is not within the scope of this document.

Potential Release Volumes

Basis - Static drain-down and total release volumes are summarized below for “Existing Valves” vs. “Existing + New Valves”. Static drain-down occurs after all valves have been fully closed. Total release volumes (static + transient) are based on a complete pipeline separation failure, or “guillotine” release, and 10-minutes response time to fully close the RCV’s. Calculations are based on the data points in Tables 4A and 4B, respectively, for static and total releases.

Bellingham & Vicinity - In the Bellingham vicinity, as defined above, the potential static-release volumes have been reduced from an average of 1,368 barrels (57,000 gallons) to 932 barrels (39,000 gallons). These represent a 32% average reduction in static drain-down in the Bellingham vicinity. Within the Bellingham City limits, the potential static drain-down volumes have been reduced by an average of 30%, from 1,150 barrels

(48,000 gallons) to 801 barrels (33,000 gallons). Potential total-release volumes are as follows: For Bellingham & vicinity, an average reduction of 1,516 barrels (64,000 gallons) from 4,179 barrels to 2,663 barrels. These represent a 41% total volume reduction. Within the approximate Bellingham City limits, an average reduction of 2,396 bbl (101,000 gallons) from 5,130 barrels to 2,734 barrels. These represent a 47% total volume reduction.

Whatcom Creek - A release in the pipeline segment from ¼-mile N of the creek to ¾-miles of the creek would have the shortest path to Whatcom Creek. Within this area, the potential static-release volumes have been reduced from an average of 1,467 barrels (62,000 gallons) to 812 barrels (34,000 gallons). These represent a 45% average reduction in static drain-down in the Whatcom Creek vicinity. Average total-release volumes are reduced by approximately 3,141 barrels (132,000 gallons) from 4,936 barrels to 1,795 barrels. These represent a 64% total volume reduction. The benefit of the new check valve at MP-16.18 is made apparent in this total volume reduction vs. the static-only reduction. This check valve backs up the existing RCV at this location and responds more quickly.

Significant reductions in potential static-release volumes have been achieved via implementation of the new valves, compared to volumes associated with existing valves only. These drainage volumes and reductions are summarized in Tables 4A, 4B, 5A and 5B, and graphically displayed in Appendix-B.

Release Analysis

Included in this section are the results of the drainage analysis and the heavier-than-air vapor analysis. Sensitive resources that appear to have the greatest potential exposure to a spill or a flammable vapor cloud are identified. Commentary assumes a spill of sufficient gasoline volume in order to reach the identified creeks or streams. The vapor discussions are based on gasoline, since a spill of diesel fuel or commercial jet fuel would not result in a flammable vapor cloud under local atmospheric conditions. The pipeline sections potentially impacting the City of Bellingham, Sections 10 through 19 as identified in Table 3, are discussed below. Referenced surface drainage maps (drawings) are found in Appendix-C.

<u>Section 10 (Milepost 10.7 – 11.5</u>) - The results of this drainage analysis are shown on Drawing M-04. Surface drainage between mileposts 10.7 and 11.1 would flow in a westerly direction. If large enough, it could enter a small stream that drains to Spring Creek, Baker Creek, Squalicum Creek and finally to Bellingham Bay. Between mileposts 11.1 and 11.4, a spill would flow in a southerly direction toward Spring Creek while a spill between mileposts 11.4 and 11.5 would flow in a westerly direction and possibly enter Spring Creek. Sensitive resources located near the drainage path include residences along Kline Road. A spill reaching the creek system would flow downstream towards Bellingham Bay. The creeks, at less than about 50 feet, are relatively narrow in width, which would prevent large pools from forming. Spring Creek is normally dry while flow in Silver Creek is slow and flow in Squalicum Creek is moderate to fast. A flammable vapor cloud from gasoline in the creek system is not expected to travel more than three hundred feet from the creek. The size of a flammable vapor cloud is expected to decrease as the gasoline proceeds downstream and evaporation takes place. Sensitive resources located near Spring and Squalicum Creeks include a child day care center located approximately two miles south of the pipeline ROW. Spring Creek also runs through the Bellingham Country Club, about 2.5 miles south of the pipeline ROW.

<u>Section 11 (Milepost 11.5-12.2</u>) - The results of this drainage analysis are shown on Drawing M-04. A depression is located southwest of the pipeline between mileposts 11.6 and 12.2. A large spill in this section may result in the formation of a gasoline pool in the depression. A spill volume sufficient to overflow the depression could enter one of the creeks listed above. Several residences are located in this area along Van Wyck Road.

Section 12 (Milepost 12.2 – 12.8) - The results of this drainage analysis are shown on Drawing M-04. Surface drainage in this area would flow toward Baker Creek and then downstream to Squalicum Creek and Bellingham Bay. Several residences are located in the drainage path near this section of the pipeline right-of-way (ROW). Several residences are also located along the creek, which normally has very little flow.

Section 13 (Milepost 12.8 – 14.3) - The results of this drainage analysis are shown on Drawing M-04. Surface drainage in this area would flow toward Squalicum Creek. There are several residences located in this drainage path, including some along Bakerview Road and Sunset Drive. Sunset Pond Park is also located adjacent to the creek.

Section 14 (Milepost 14.3 - 15.8) - The results of this drainage analysis are shown on Drawing M-05. Surface drainage in this area would flow into a developed neighborhood located to the west and into a creek, which flows to Whatcom Creek. There are numerous residences located in this drainage path. Two child day-care centers and the Highland Heights Park are also located here. Residences are also located east of and near the pipeline ROW, and south of and near the drainage path. Whatcom Creek flows to Bellingham Bay. Flow in the creek is relatively fast until it reaches the Bay, where it becomes tidal. Numerous residences and businesses are located along the creek.

Section 15 (Milepost 15.8 – 16.7) - The results of this drainage analysis are shown on Drawing M-05. Surface drainage in this area would flow towards Whatcom Creek. There are several residences located in the northern portion of this drainage path, and a middle school is near the path. Whatcom Falls Park, Whatcom Falls Trout Hatchery, and the City of Bellingham Water Treat Plant are located on the pipeline ROW near OPL milepost 16. As stated above, Whatcom Creek flows through the City of Bellingham where numerous residences and businesses are located adjacent to the creek.

Section 16 (Milepost 16.7 – 18.7) - The results of this drainage analysis are shown on Drawings M-05 and M-06. Surface drainage in this area would flow in a northwesterly direction toward a creek located approximately 1,000 to 2,000 feet west of the pipeline. Residences are located in the northern portion of this drainage path, and a child day care center is near the creek. Clearbrook Park is located on the ROW at OPL milepost 17. In addition, there are several residences located west of and adjacent to the creek. The creek flows north then northwest into Whatcom Creek.

Section 17 (Milepost 18.7 - 19.2) - The results of this drainage analysis are shown on Drawing M-06. Surface drainage in this area would be to the west, towards a creek that flows in a southwesterly direction into Lake Padden. This creek varies from 1,500 ft. to 3,000 ft. from the pipeline. Lake Padden Estates is located on OPL milepost 19 of the ROW. Lake Padden Golf Course is partially located in the drainage path of a potential spill of sufficient volume as well as being adjacent to the creek and Lake Padden. Flow in the creek leading to Lake Padden is low. Flow out of Lake Padden is via Padden Creek, which flows in a westerly direction through the City of Bellingham to Bellingham Bay. Flow velocity is moderate. Numerous residences and businesses are located adjacent to Padden Creek. It is likely that response strategies could prevent released gasoline from leaving Lake Padden and entering Padden Creek.

Section 18 (Milepost 19.2 - 20.2) - The results of this drainage analysis are shown on Drawing M-06. Surface drainage in this area would flow in a southwesterly direction toward an unnamed creek and then northwesterly into Lake Padden. Flow in this unnamed creek is slow. Lake Padden Park and Lake Padden Golf Course are located on the pipeline ROW near OPL milepost 20. The golf course is also located adjacent to the unnamed creek and Lake Padden.

Section 19 (Milepost 20.2 - 21.5) - The results of this drainage analysis are shown on Drawing M-06. Surface drainage in this area would flow in a northerly direction towards Chuckanut Creek, located up to one-mile downhill from the pipeline. Chuckanut Creek then flows in a westerly direction into Chuckanut Bay. The flow in Chuckanut Creek is slow. Chuckanut Falls and Chuckanut Canyon Mobile Parks are located on the pipeline ROW near OPL milepost 21. Numerous residences are located along Chuckanut Creek, including those located in Chuckanut Village near the outfall of the creek.

In conclusion, the greatest risk from a sufficient gasoline release from the pipeline in or near the City of Bellingham, if it were to occur, would be in the 2.5 mile section located between OPL mileposts 14.5 and 17. This includes parts of drainage Sections 14, 15, and 16 with “critical” rankings of 1, 2, and 3, respectively. This area contains a large number of residences and several day care centers and parks located directly within the potential surface-drainage path. A sufficient release of gasoline could pass very near these sensitive resources. If released gasoline reaches one of the creeks in the area, it would follow the creek flow. This would force the gasoline into a narrow flow pattern governed by the width of the stream. While the gasoline flowing in the creek would still produce flammable vapors, its surface area would be limited, thereby reducing the amount of evaporating material forming the cloud. It is also noted that a flammable gasoline vapor cloud would extend only downwind from the release point or liquid source. If the wind were blowing perpendicular to a creek carrying a gasoline spill, a flammable cloud would extend along the length of the creek where gasoline is present, dispersing away from it. If the wind were blowing parallel to a creek carrying a gasoline spill, then the flammable vapor cloud would be relatively narrow and located along the creek. The cloud could be either upstream or downstream from the spilled gasoline, depending on the direction of the wind. Since gasoline vapors are heavier than air, they would tend to stay low to the ground and spread out as they are blown toward a hill. They would tend to move toward low areas and follow canyons while moving with the wind.