Maritime Simulation Model of San Francisco Bay

Explanation of Exposure Results

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1. Description of Base Case Scenario and future scenarios

We will start our discussion of the results of the simulation analysis with some basic comparisons to the Base Case. This case represents the operation of ferries in the San Francisco Bay area during the year 2000. This will be used as a reference point to compare the proposed alternatives and to give an understanding of the traffic patterns currently seen by ferries in the study area. In the Base Case simulation, the ferries follow the schedules for the year 2000, other VTS traffic follows the US Coast Guard VTS data for the year 2000 while recreational special events follow year 2001 supplied by the USCG. Wind direction and speed are taken from hourly observations from NOAA weather buoys data for the year 2000. Visibility conditions are generated following a meteorological model by Sanderson (Meteorology at Sea, Stanford Maritime Limited, 1982), which utilizes hourly air temperature data and water temperature data for the year 2000. These visibility conditions are calibrated to quarterly percentage of times that vessels operate in restricted visibility in the locations Golden Gate, South Bay, San Pablo Bay and Grizzly Bay. These percentages were obtained using US Coast Guard Coast Pilot data combined with expert judgment elicited data from VTS operators and San Francisco Pilots following an elicitation process known as the Analytical Hierarchy Process.

The Base Case will be compared to three proposed future scenarios. These scenarios in order of consideration for future implementation are

- Alternative 3: Enhanced Existing System
- Alternative 2: Robust Water Transit System
- Alternative 1: Aggressive Water Transit System.

For each of these scenarios the routes for the ferries follow the maps created for each alternative supplied by URS Corporation, while their schedules follow the spreadsheets supplied. If there were any discrepancies between the two, then we took the spreadsheet as the master. In addition two the four scenario's Base Case, Alternative 3, Alternative 2 and Alternative 1 we ran two additional scenario's that focus on those ferry to vessel interactions that occur in restricted visibility

- Base Case – BVI
- Alternative 3 – BVI

where the acronym BVI denoted Bad Visibility Interaction. In prior risk assessment studies that we have conducted (the Washington State Ferry Risk Assessment and the Prince William Sound Risk Assessment) interactions of vessels in restricted visibility were found to be more risky than interactions in good visibility. The unique visibility conditions in the San Francisco Bay combined with our prior experience in other studies prompted us to run these analyses.

2. Synopsis of Analysis Results

Table 1 gives some basic comparisons of the three alternative cases to the Base Case. In the Base Case 97% of the total ferry to traffic interactions observed in the study area occur in 20% of the geographic area of the san Francisco bay that observe ferry to traffic interactions in the first place.

Table 1. Percentage comparisons to the Base Case under various criteria.

	% Base Case Ferry Transits	**% Base Case Grid Cells Covered**	**# Base Case Total Interactions**	**% Base Case Interactions in 20% of Cells**
Base Case	100%	100%	100%	97%
Alternative 3	365%	120%	620%	600%
Alternative 2	1228%	230%	4600%	4500%
Alternative 1	1559%	240%	8400%	8200%

Alternative 3 has 3.65 times as many transits as the Base Case, but covers only a little larger area, with 20% more grid cells having at least one interaction in them in the simulation. In all over 6 times as many interactions occur in Alternative 3 than occurred in the Base Case, while the coverage area of these interactions only increases by a factor of 1.2. Furthermore, 20% of the grid cells in Alternative 3 have 6 times as many interactions as all the grid cells in the Base Case put together. Thus Alternative 3 makes the current operating area more congested with more interactions.

Alternative 2 has 12.3 times as many transits as the Base Case, but covers a much larger area, with 2.3 times as many grid cells having at least one interaction. In all over 46 times as many interactions occur in Alternative 2 than occurred in the Base Case. Furthermore, 20% of the grid cells in Alternative 2 have 45 times as many interactions as all the grid cells in the Base Case put together. Thus Alternative 2 makes increases the operating area from the Base Case and leaves the system much more congested with many more interactions.

Alternative 1 has 15.6 times as many transits as the Base Case, but covers only a little larger area than Alternative 2, with 2.4 times as many grid cells having at least one interaction than in the Base Case. In all over 84 times as many interactions occur in Alternative 1 than occurred in the Base Case. Furthermore, 20% of the grid cells in Alternative 1 have 82 times as many interactions as all the grid cells in the Base Case put together. Thus Alternative 1 makes increases the operating area by about the same factor as Alternative 2, but significantly increases congestion with many more interactions compared to Alternative 2.

Figure 1 below summarizes the analysis in Table 1 described above. Observe from Figure 1 that the number of ferry to vessels interactions growths exponentially with the number of ferry transits.

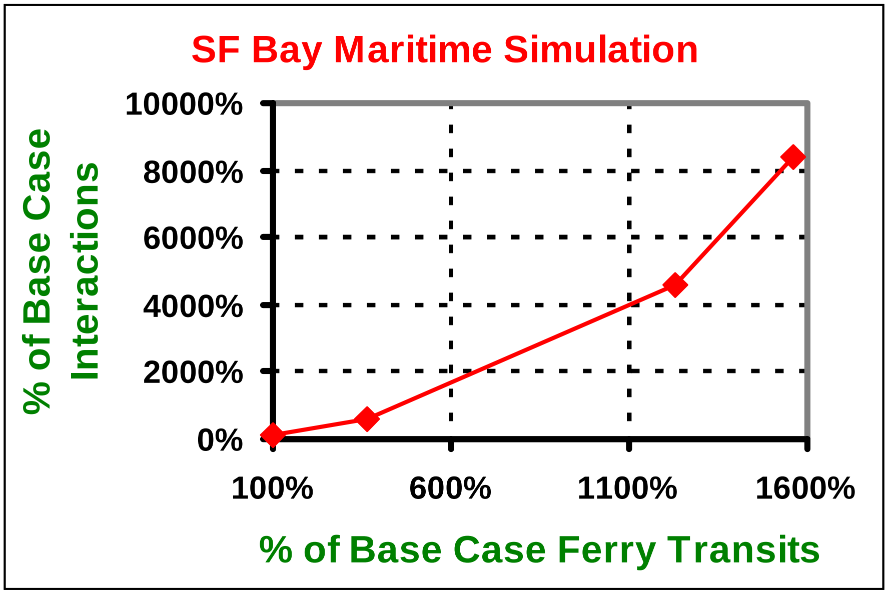

Figure 1. Exponential Growth in The full Base Case simulation results.

3. Description of Graphical Output Format

Figures 2 through 5 show the full simulation output for the Base Case and each alternative case. Figure 1 and the following figures are quite complex, in that they attempt to convey all the results in one figure. Thus we will examine the pieces one by one. The simulation is used to count interactions between ferries and other vessels. The analysis is broken down across a grid of approximately ¼ mile by ¼ mile cells. The cells are color coded in the figure to represent the number of interactions that occur in that cell over the 1-year simulation time. Both the cell containing the ferry and the cell containing the interacting vessel are recorded; hence the colored cells away from the ferry routes.

To the right of each figure, the legend gives an interpretation to the color-coding of the cells. The scale goes from blue, with the fewest interactions, to black with the most interactions. Thus a black cell has the most interactions of any cells in the Base Case simulation. This maximum is used as a reference point for the legend. The percentages shown in the legend are calculated as a percentage of this maximum number of interactions. For example, an orange cell has an interaction count that is only 3% of the maximum number of interactions observed in a grid cell in the Base Case. A solid black cell has the same of more interactions than any cell in the Base Case (that is the solid black cell in the Base Case identifies that cell with the most interactions in the Base Case).

Another reference scale is also provided. The average number of interaction per cell in the Base Case has 1.68% of the maximum number of interactions in a cell observed in the Base Case. Returning to our example, an orange cell has 1.78 times the number of interactions seen in the average cell in the Base Case. A solid black cell, with the most interactions, has over 60 times as many interactions as the average in the Base Case, indicating that some cells are highly congested when compared to the average. One can also see that the legend is not numerically linear. As some of the cells are much more congested than others, we have had to grade the scale. To allow for the wide disparity in interactions in grid cells across the simulation, the scale is graded on a curve. Examining the Figures 2 through 4 for the alternative cases, one can see that the legend has not changed to allow easy comparison.

The graph provided in the middle of figures contains the information earlier provided in Table 1. The horizontal axis describes the coverage area of the interactions compared to the base case coverage area. For example, from the purple line in the central graph of Figure 2 it may be observed that the coverage area of interactions in Alternative 3 is approximately 1.2 times the coverage area of the Base Case. The vertical axis describes the total number of interactions observed compared to the Base Case. For example, from the purple line in the central graph of Figure 2 it follows that approximately 6.2 times as many interactions are observed in the Alternative 3 than in the Base Case. The fourth column in Table 1 was constructed by focusing on 20% of total base case grid cells on the horizontal axis in Figures 1 through 4.

4. Detailed Description of Results

We turn our attention to the map of the study area, zooming in on the central Bay area in Figures 8 through 13. The ferry routes are shown in colors representing the Scenarios. For the Base Case in Figure 8, the majority of the dark colored grid cells are in the central Bay area, particularly close to the Ferry Building. In fact if we take the red square around the Ferry Building, almost 53% of all the interactions in the Base Case occur in this area. This is the area with most ferries operating, a great deal of other VTS Traffic and organized recreational events combined with the worst visibility for a large part of the year (especially in the July, August and September).

Figure 9 once again zooms in on the central Bay area for Alternative 3. Notice that the same red square around the Ferry Building now contains 3.7 times as many interactions as the whole Base Case and that much of the area is now colored solid black, indicating that there are more interactions in that grid cell than the maximum for any grid cell in the Base Case. It is also useful to point out that in the schedule spreadsheets supplied to the George Washington University, there was a schedule for the Alameda Bay to Mission Bay route, even though this route was not included in the original map for Alternative 3. This route is shown in pink to highlight our decision to follow the spreadsheet. All other routes are shown in blue over the colored grid cells.

Figure 10 zooms in on the central Bay area for Alternative 2. Notice that the same red square around the Ferry Building now contains 17 times as many interactions as the whole Base Case and again much of the area is colored solid black, indicating that there are more interactions in that grid cell than the maximum for any grid cell in the Base

Case. Figure 11 zooms in on the central Bay area for Alternative 1. Notice that the same red square around the Ferry Building now contains 27 times as many interactions as the whole Base Case and yet again much of the area is colored solid black, indicating that there are more interactions in that grid cell than the maximum for any grid cell in the Base Case.

Figures 12 and 13 show the interactions that occur in bad visibility in the Base Case and Alternative 3. Figure 12 shows that 18% of the interactions in the Base Case are in bad visibility, with a third of these being in the red square around the Ferry Building. However, Figure 13 shows a much different picture for Alternative 3. More interactions occur in bad visibility in Alternative 3 than occur in all conditions in the Base Case with over half of these in the red square around the Ferry Building. Overall the map shows high densities of interactions in bad visibility over a large area. Of particular concern should be the solid black cells in the red square of Figure 13 indicating as least as many interactions in bad visibility in Alternative 3 in these cells compared to the maximum number of interactions observed in any cell in the Base Case regardless of visibility conditions.

5. Recommendations based on Exposure Analysis

To provide time and budget to:

1. Run simulation exposure analyses for the entire period August 1998 – December 2001 and develop output results in the format of this report for that period.
2. Present the subsequent analyses results for the extended period to stakeholders and resolve or explain the observation of anomalies.
3. Use the results of the extended simulation exposure analyses in a Probabilistic Risk Assessment (PRA) similar to that of the Washington State Ferry Risk Assessment, where output analyses is presented in terms of expected number of accidents per year.
4. Consider the current San Francisco Bay Ferry Operations and future planned ferry operations as a Maritime Transportation System (MTS) rather than a collection of individual ferry routes by:
    - Designing a ferry traffic routes system that allows for increased ferry traffic while limiting the increase in expected number of accidents per year.
    - Designing ferry schedules utilizing this ferry traffic route system that allow for increased ferry traffic while limiting the increase in expected number of accidents per year. A consideration in the development of these future schedules should be the time between arrivals and departures at ferry terminals to allow for sufficient time of loading an unloading passengers.
5. Develop and investigate risk intervention measures that target reduction of incidents (e.g. human error, mechanical failures, etc.) and reduction of accidents (e.g. collisions, allisions, etc.) given an incident occurred, in addition to reduction of exposure targeted under item 4. Examples of such risk intervention measures

are reducing human error through training, two officers on the bridge and external vigilance.

6. Develop and investigate risk intervention measures that target reduction of immediate and/or delayed consequences (e.g. fatalities, equipment loss, etc.) given an accident occurred, in addition to the prevention measures under 4 and 5. Examples of such risk intervention measures are emergency rescue, fire fighting, and emergency medical assistance.
7. Perform an uncertainty analysis of accident risk and risk intervention evaluation to provide estimates of annual accident risk end risk intervention effectiveness in terms of probability intervals rather point estimates.

> *"The truth is that we are uncertain. The language of uncertainty is probability. Therefore, speaking the truth means to develop analyses results in terms of probability curves rather than in terms of point estimates". Stan Kaplan, "THE WORDS OF RISK ANALYSIS", Risk Analysis, Vol. 17, No. 4, 1997*

6. Disclaimer

In our experience development of analysis results is an iterative process of interactions with stakeholders and the people we work for. Anomalies that are observed in the analysis are either explained or resolved. Unfortunately. time schedule and budget did not allow for such a process. Running analysis for the year 2000 generated the maritime simulation model results herein. The maritime simulation model was prepared to develop analysis results by running exposure analyses for the period August 1998 – December 2001. Time schedule did not allow for the analyses over the extended period. One simulation run of the Alternative 1 Scenario for the extended period takes over 72 hours on a high end personal computer. A full analyses over this period would still be running at the time this report is written. Our requirement to deliver prior to July 15 COB necessitated to shorten the analyses period to the year 2000 only.

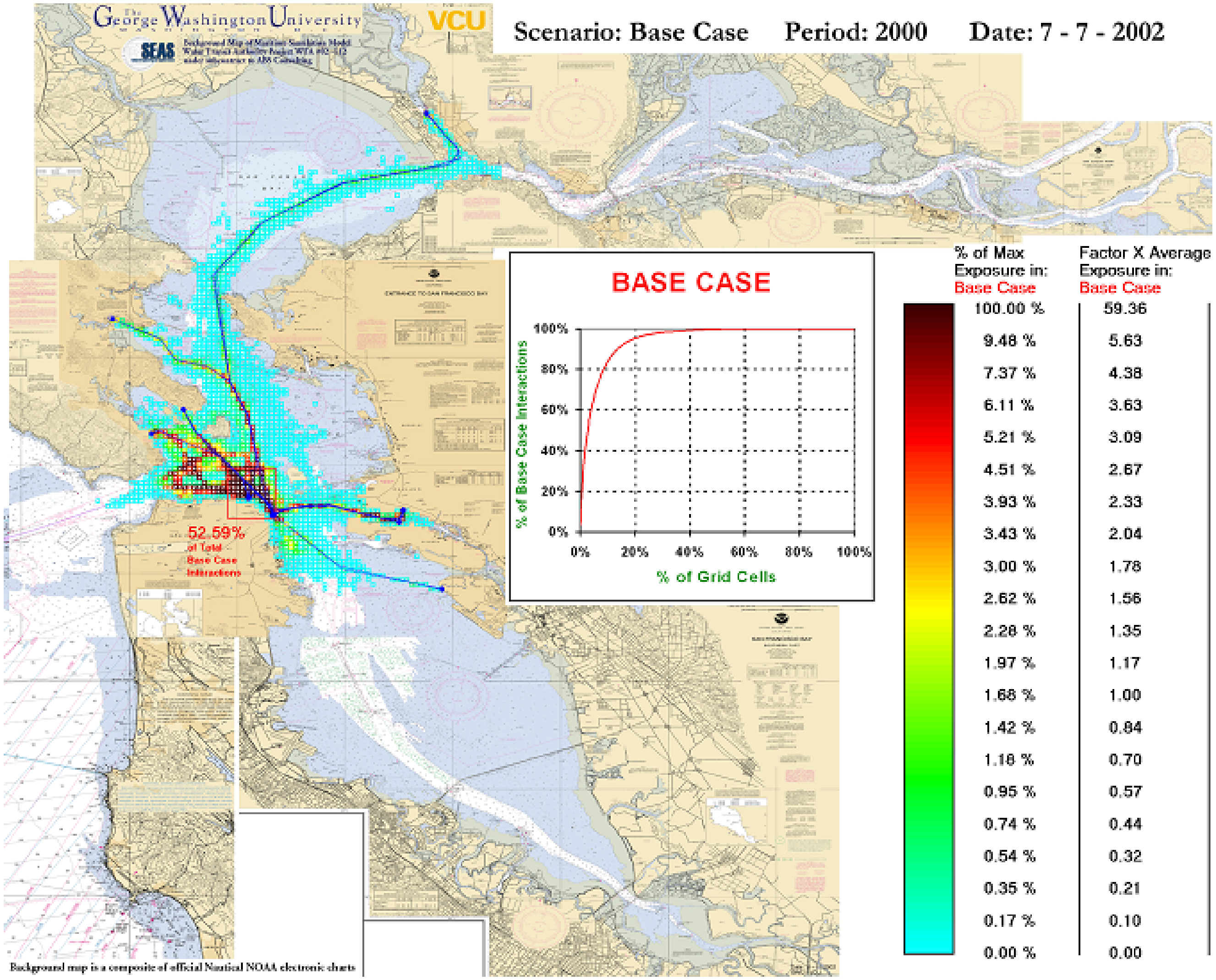

Figure 2. The full Base Case simulation results.

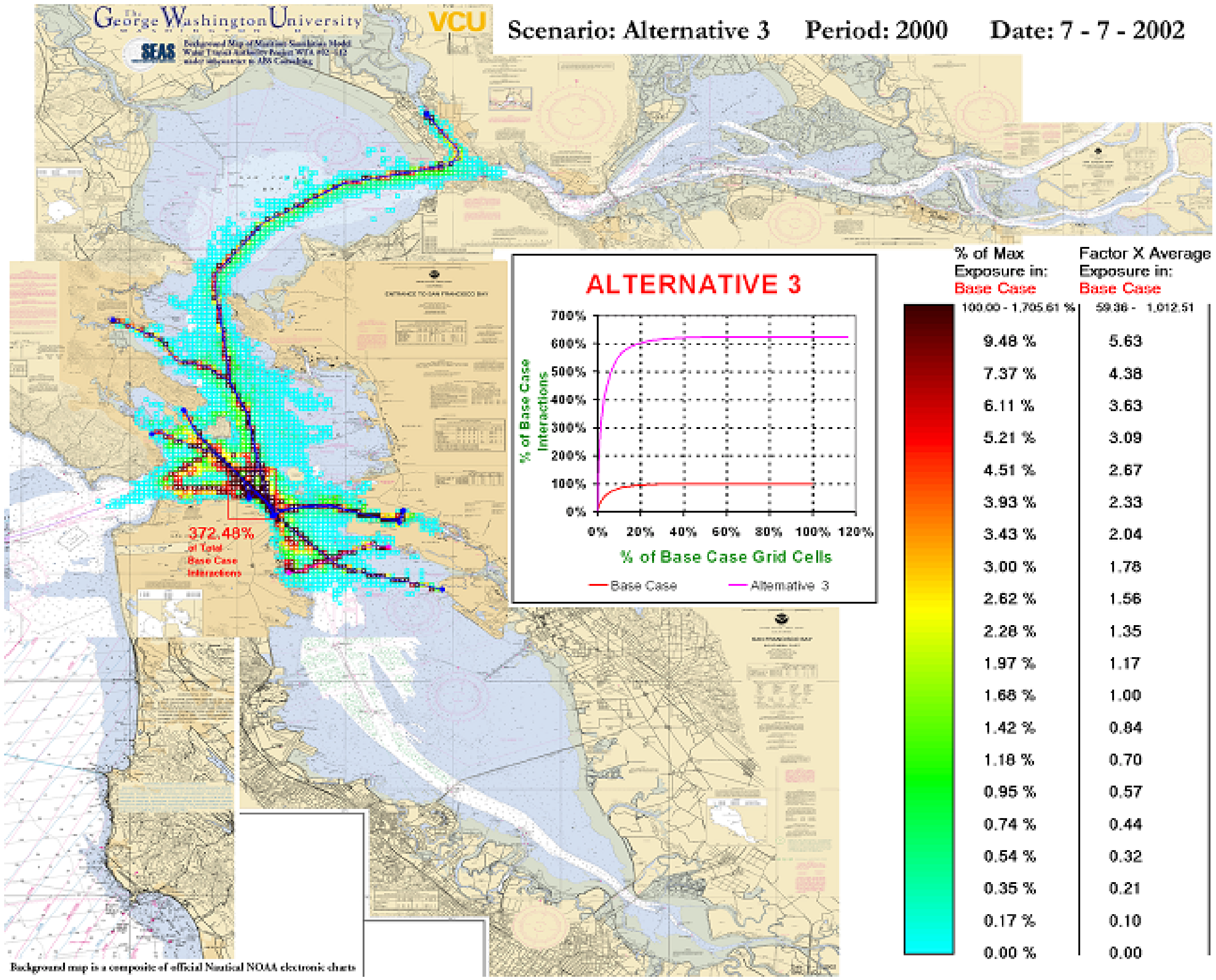

Figure 3. The full Alternative 3 simulation results.

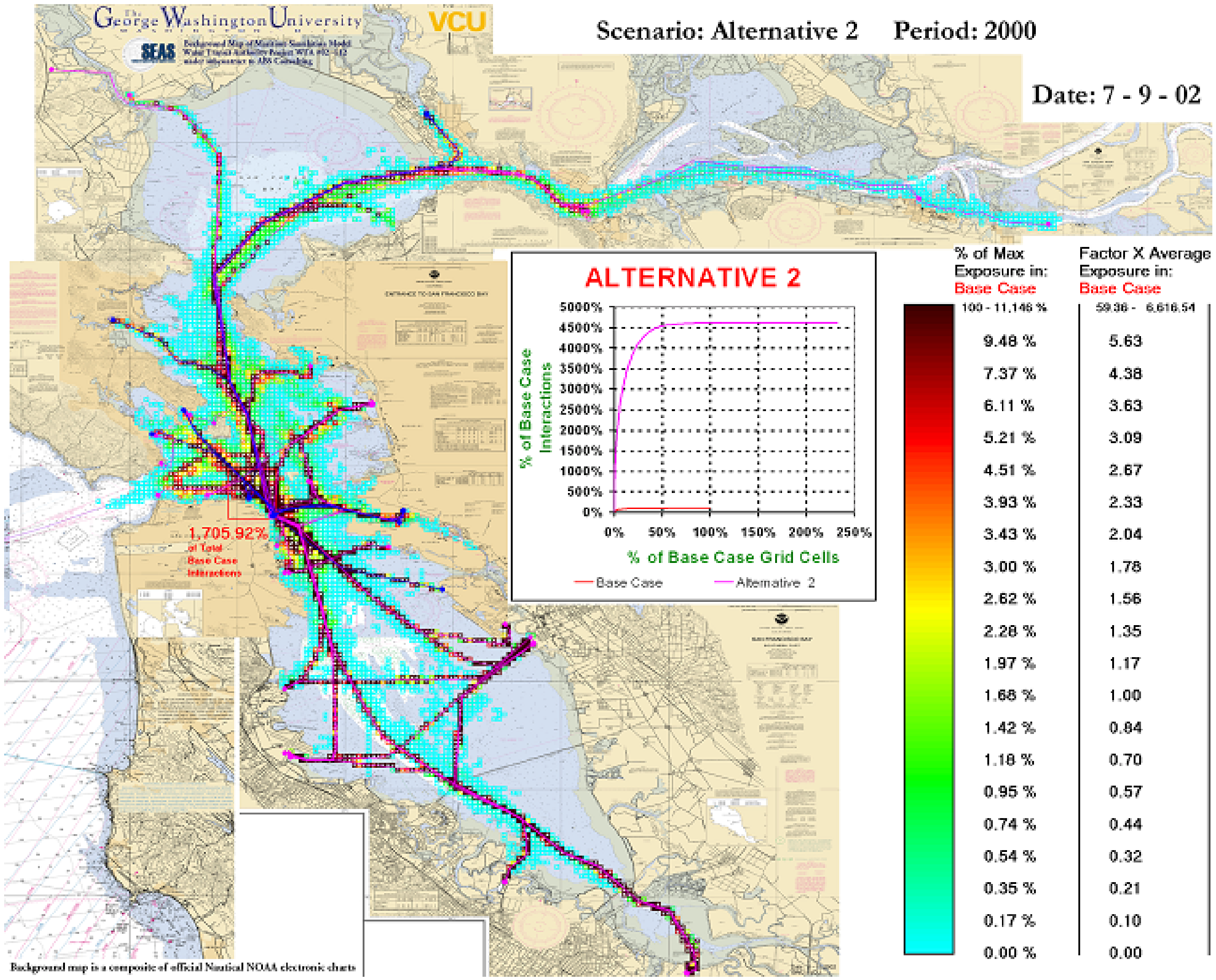

Figure 4. The full Alternative 2 simulation results.

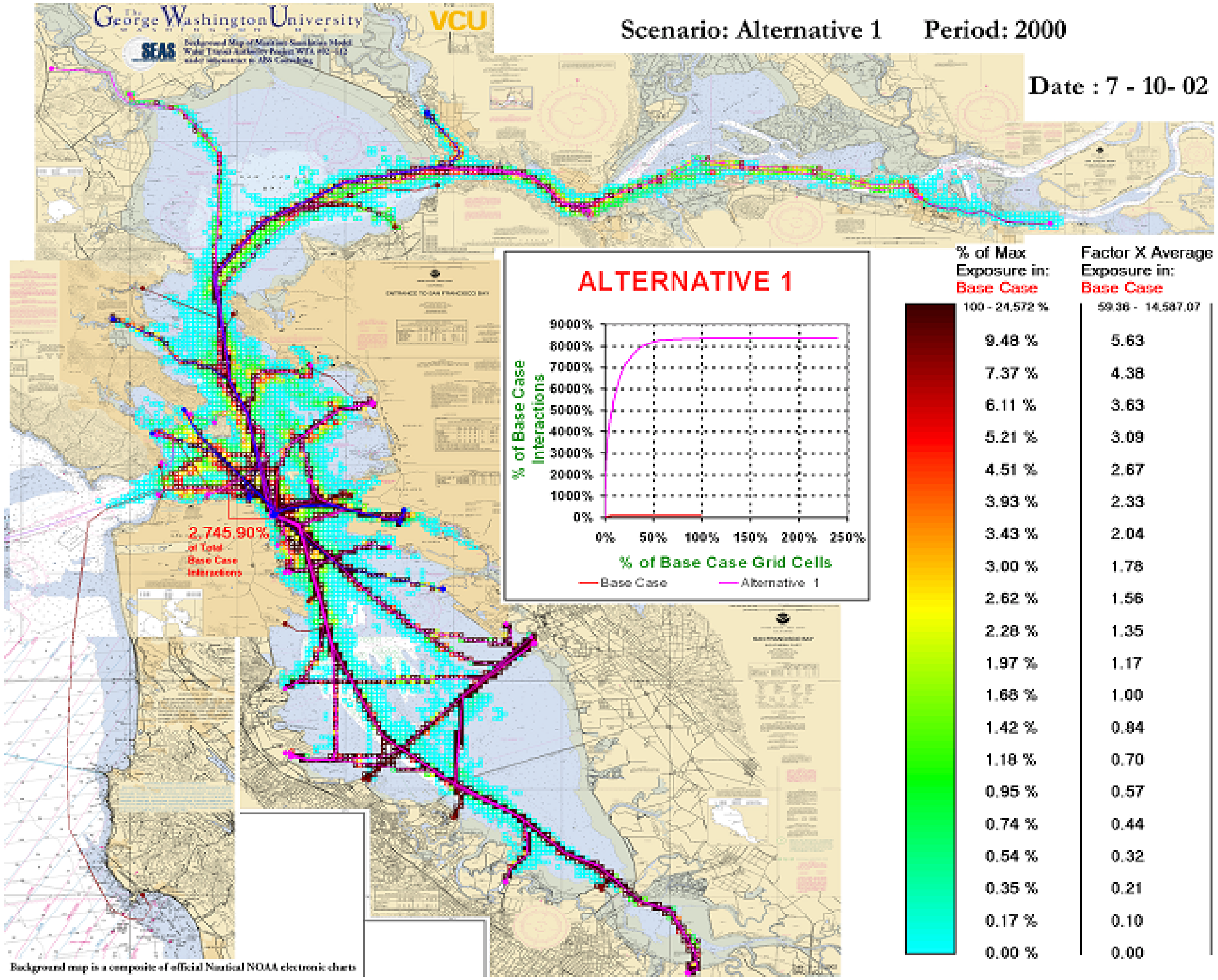

Figure 5. The full Alternative 1 simulation results.

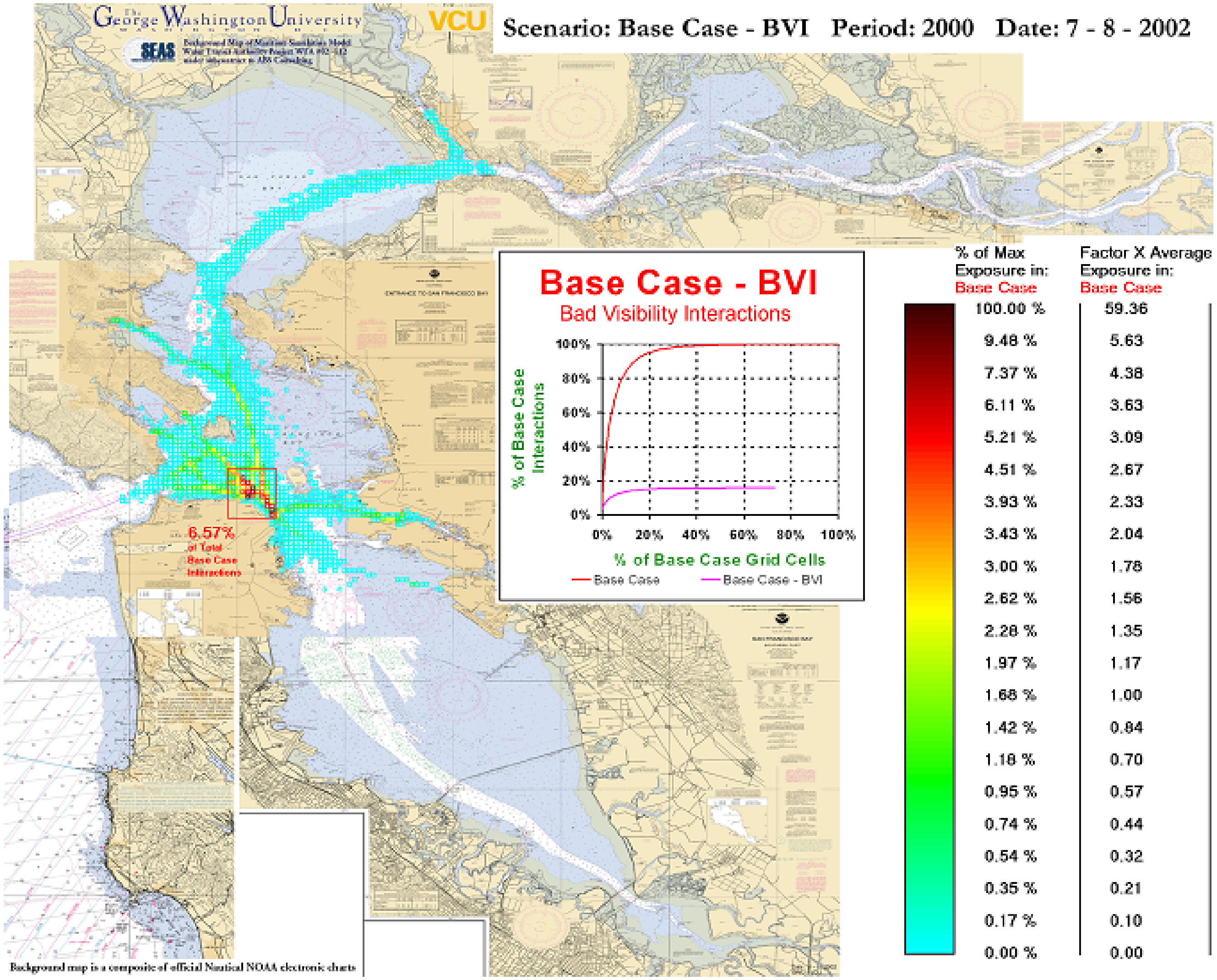

Figure 6. The Base Case simulation results in bad visibility.

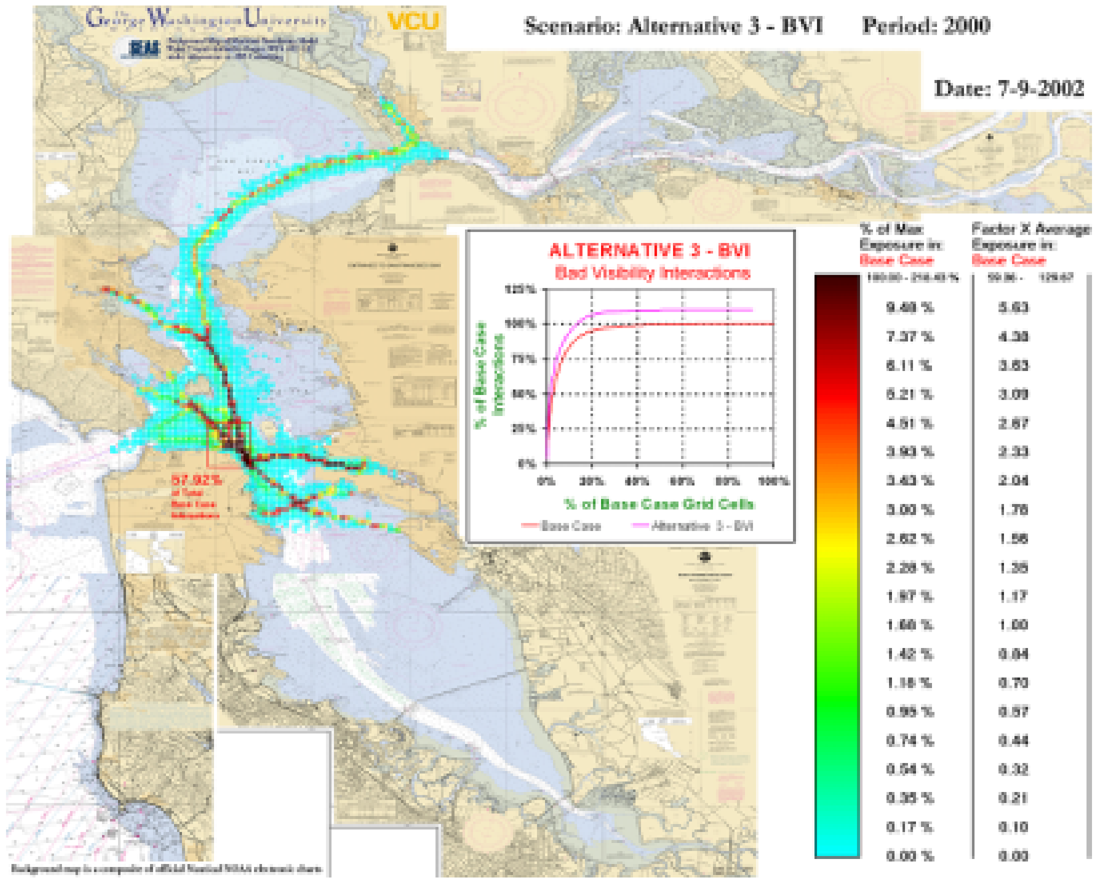

Figure 7. The Alternative 3 simulation results in bad visibility.

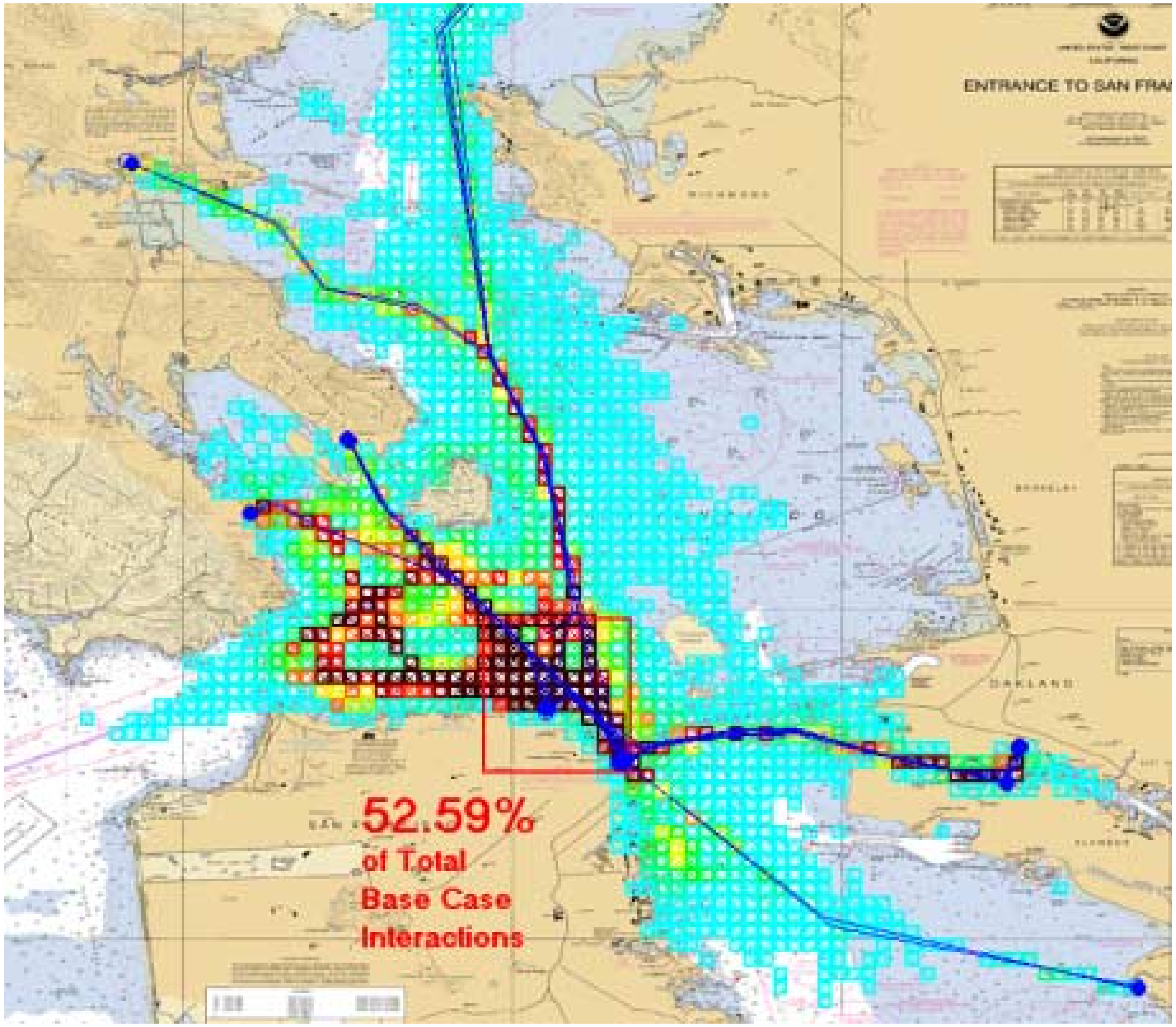

Figure 8. Zooming in on the Base Case simulation results.

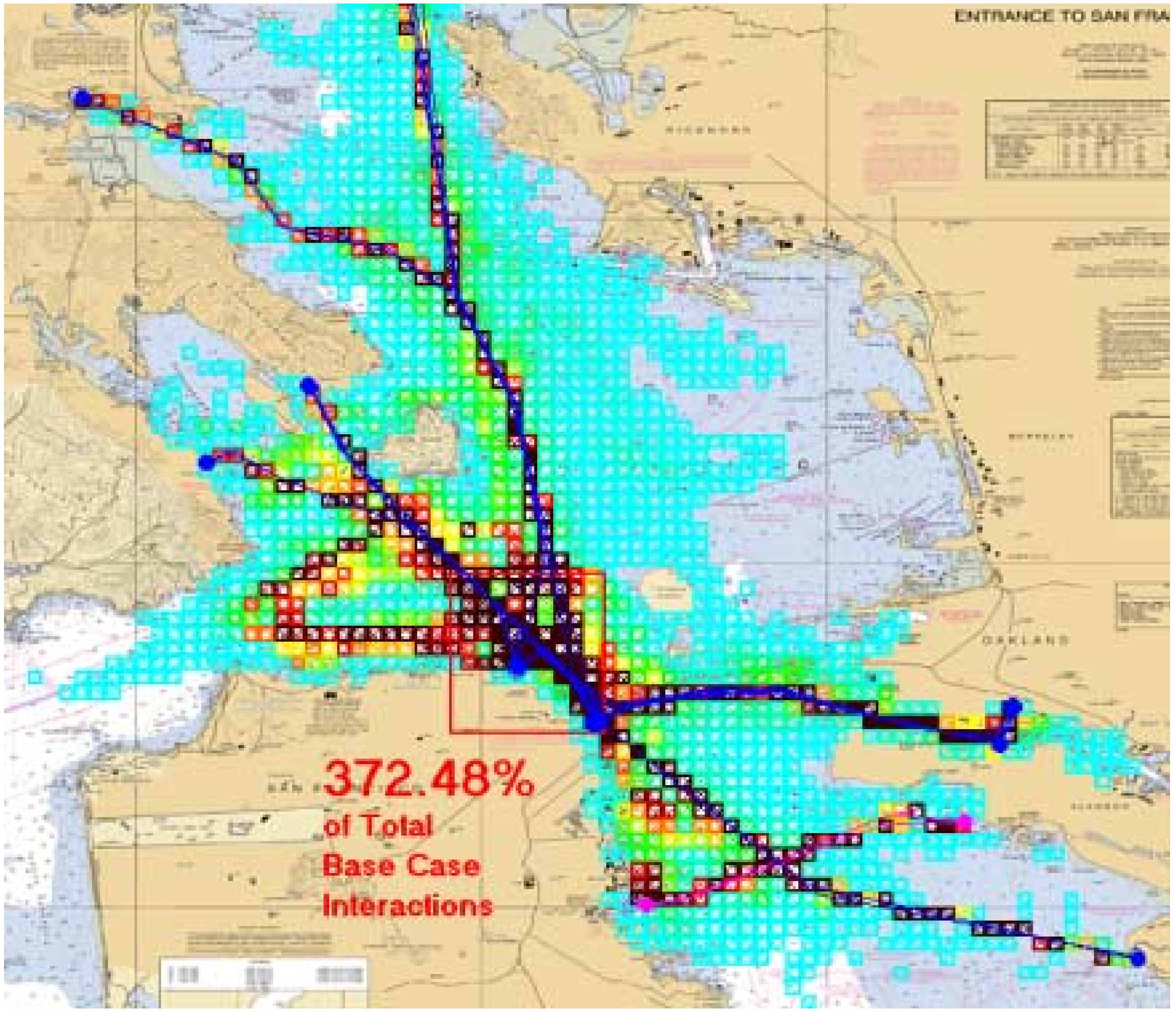

Figure 9. Zooming in on the Alternative 3 simulation results.

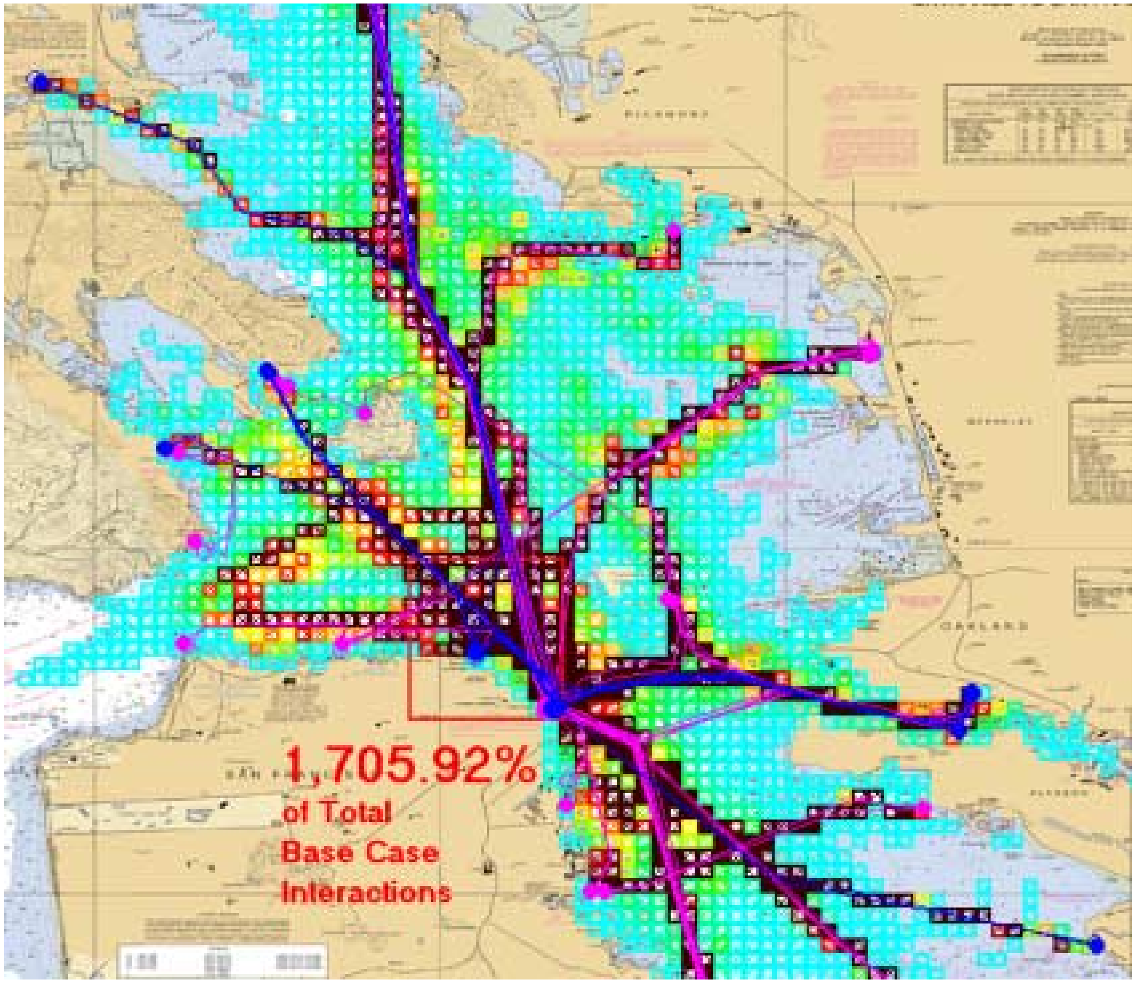

Figure 10. Zooming in on the Alternative 2 simulation results.

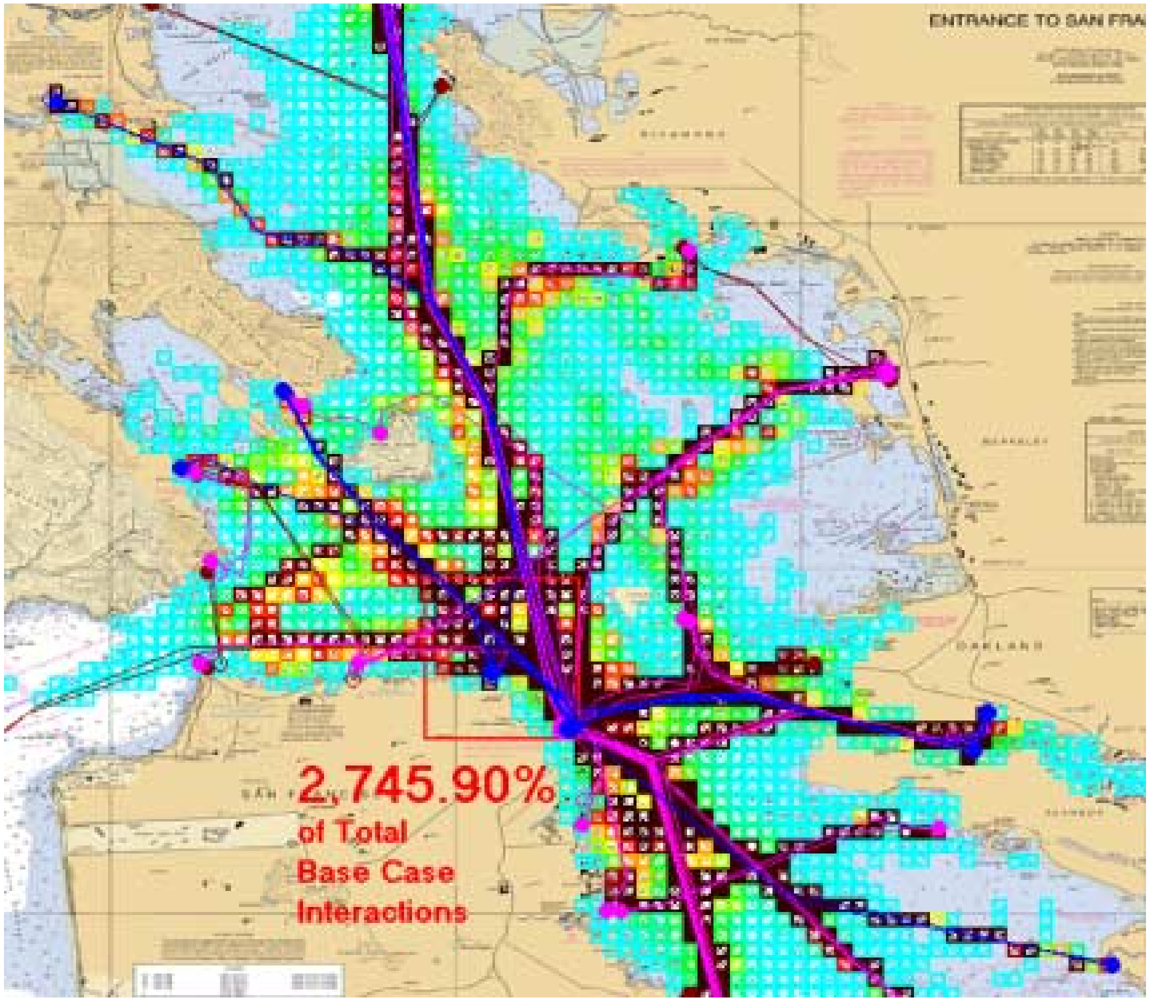

Figure 11. Zooming in on the Alternative 1 simulation results.

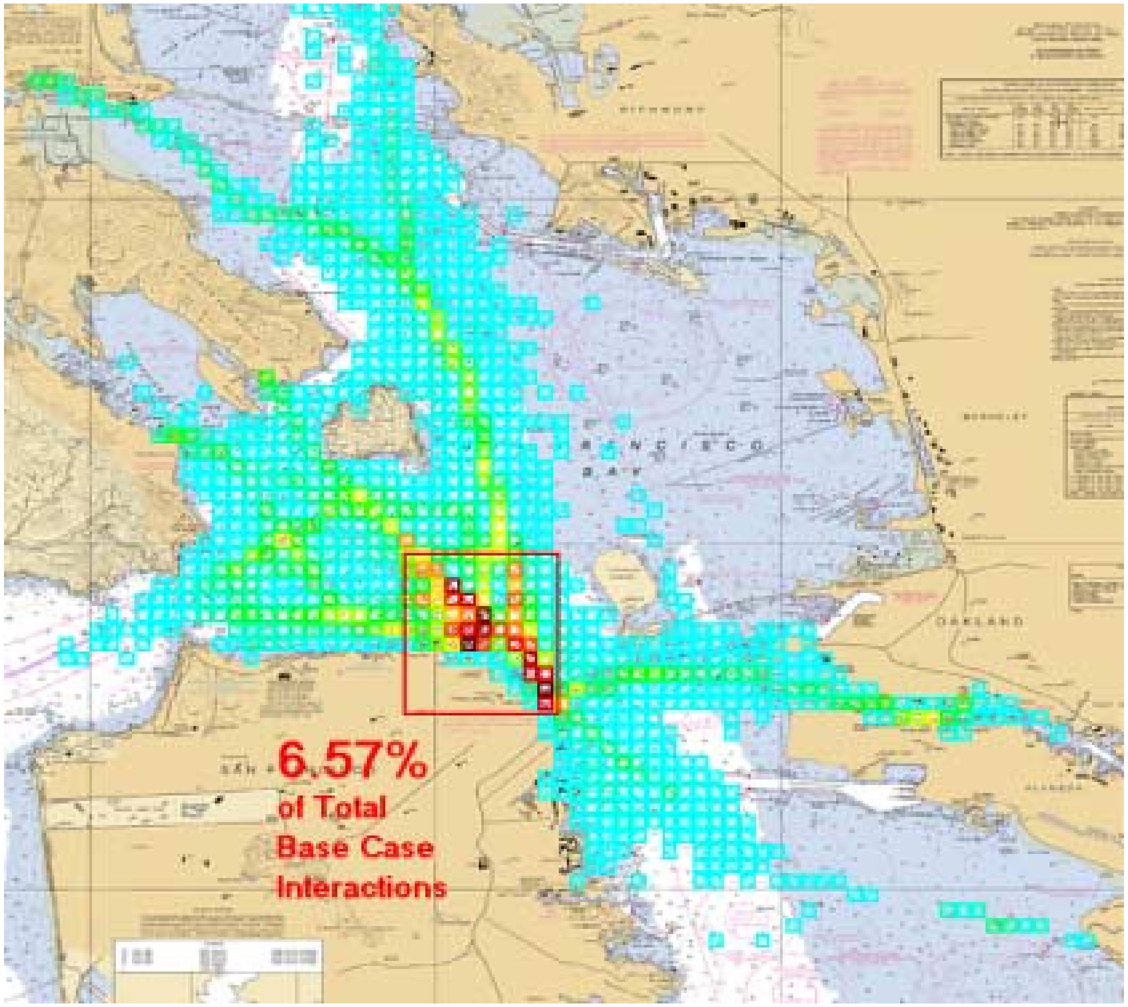

Figure 12. Zooming in on the Base Case simulation results in bad visibility.

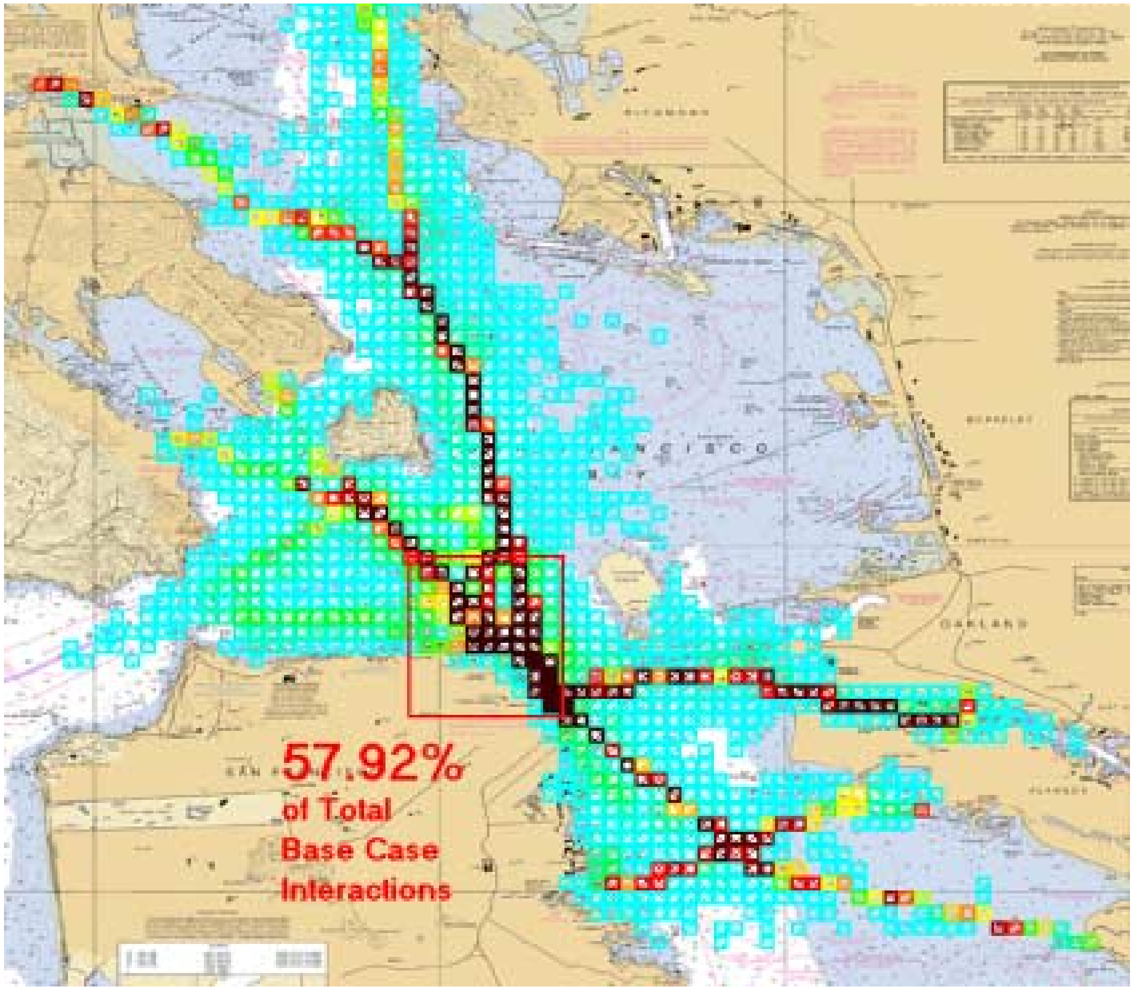

Figure 13. Zooming in on the Alternative 3 simulation results in bad visibility.