A Traffic Density Analysis of Proposed Ferry Service Expansions in San Francisco Bay Utilizing Maritime Simulation

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Statistical Sciences And Operations Research Department

VCU

Introduction

- To relieve congestion on highways, the state of California is proposing to expand ferry operations on San Francisco (SF) Bay by
  - phasing in up to 100 ferries in addition to the 14 currently operating,
  - extending the hours of operation of the ferries,
  - increasing the number of crossings
  - employing some high-speed vessels.

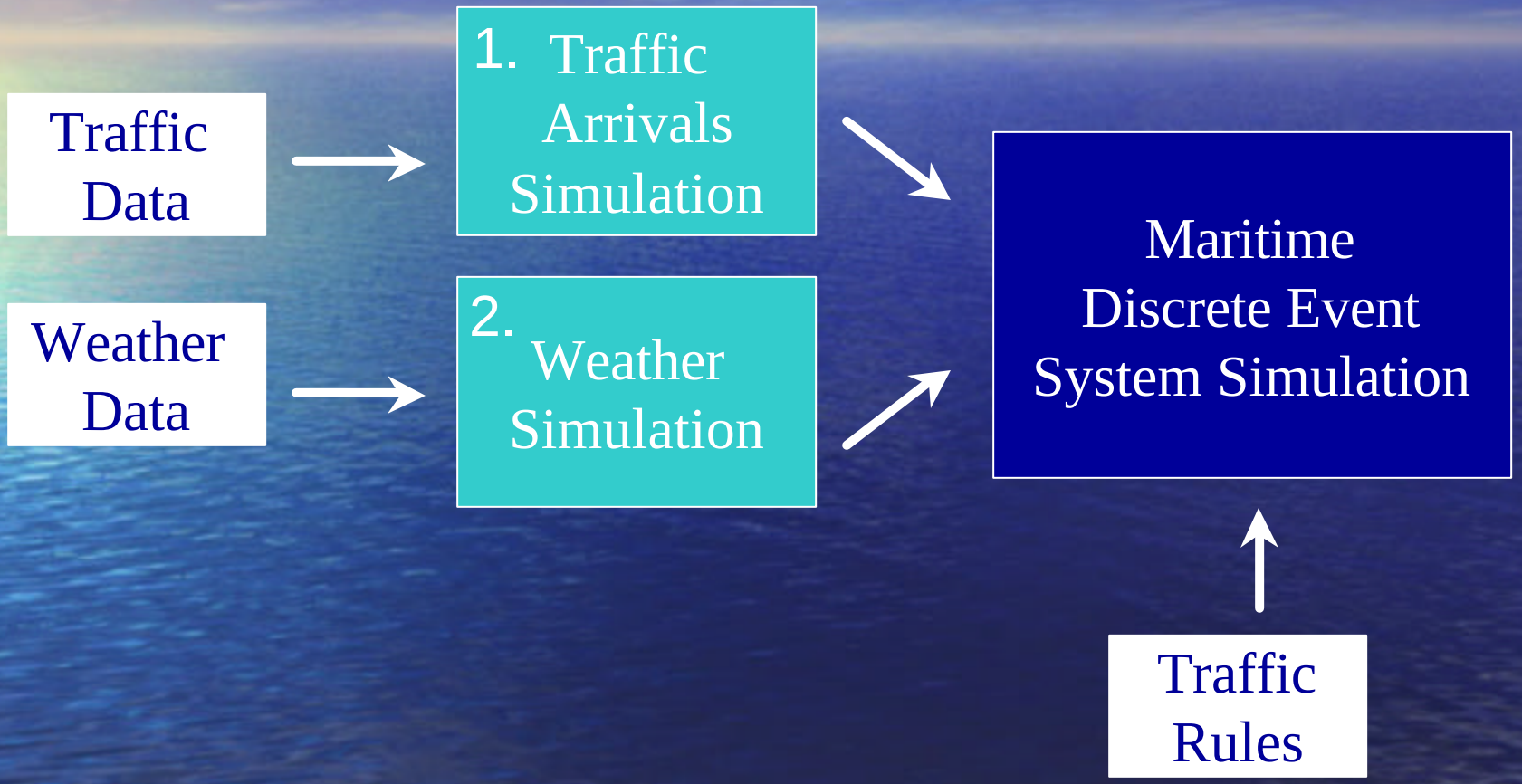
San Francisco Bay Water Transit Authority (WTA) is tasked to investigate whether this can be done in a safe manner?

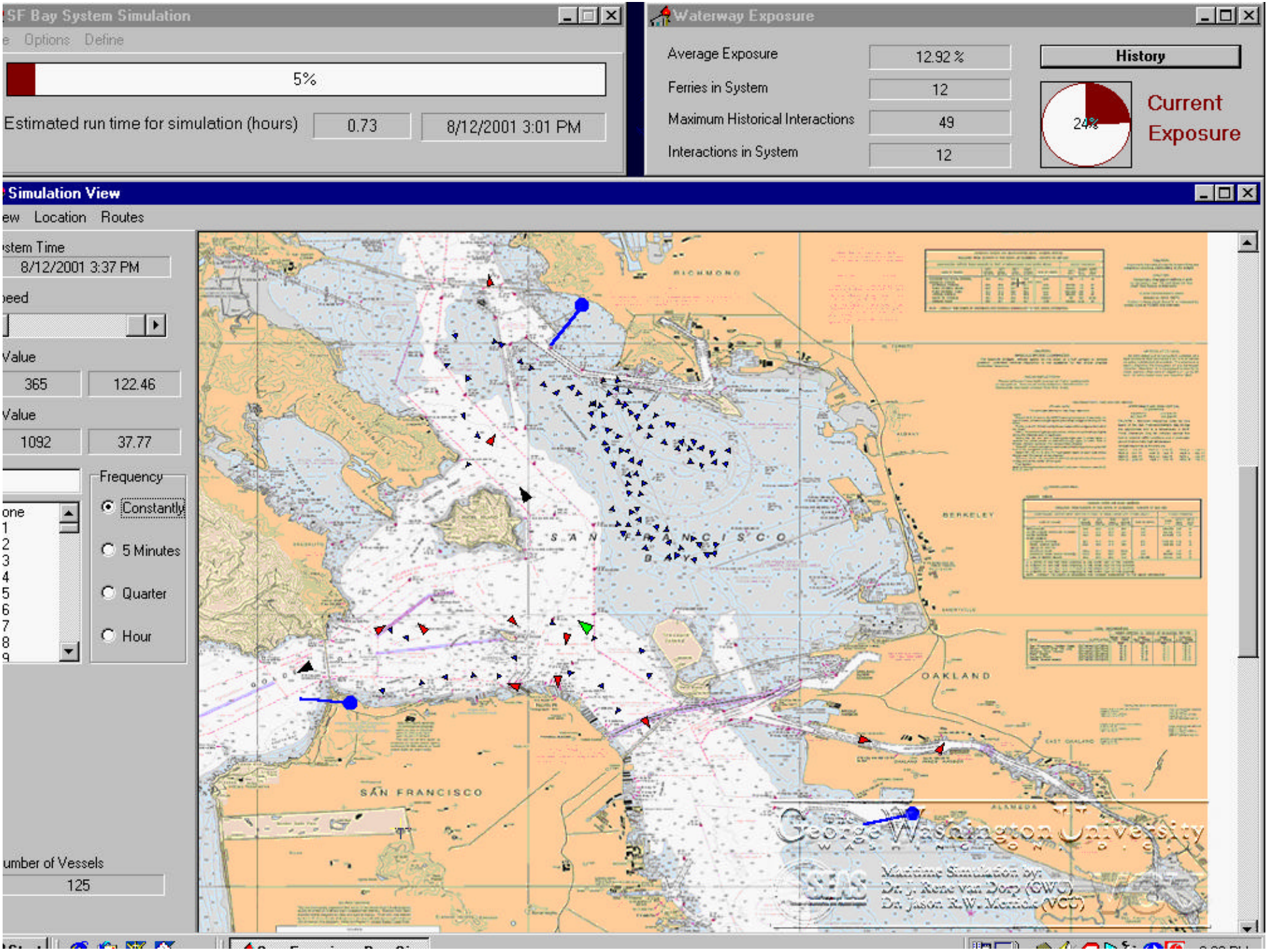
Three Future Ferry Service Scenarios

- Alternative 3: Enhanced Existing System (Least Aggressive Expansion)
- Alternative 2: Robust Water Transit System
- Alternative 1: Aggressive Water Transit System (Most Aggressive Expansion)

WTA asked us (GWU-VCU) to build a Maritime Simulation to help address the safety question

Maritime System Simulation




SF Bay System Simulation
Options Define
5%
Estimated run time for simulation (hours)
0.73
8/12/2001 3:01 PM
Waterway Exposure
Average Exposure
12.92 %
Ferries in System
12
Maximum Historical Interactions
49
Interactions in System
12
History
24%
Current Exposure
Simulation View
Location Routes
Time
8/12/2001 3:37 PM
Value
365
122.46
Value
1092
37.77
Frequency
Constantly
5 Minutes
Quarter
Hour
Number of Vessels
125
RICHMOND
BERKELEY
SAN FRANCISCO BAY
OAKLAND
SAN FRANCISCO
ALAMEDA
George Washington University
Maritime Simulation by:
Dr. J. Rene van Dorp (GWU)
Dr. Jason R.W. Merrick (VCU)

Outline

- Building the Simulation (Modeling Traffic)
- Building the Simulation (Modeling Weather)
- Counting Interactions in a Maritime Simulation
- Results
  - Base Case
  - Alternatives 1, 2 and 3

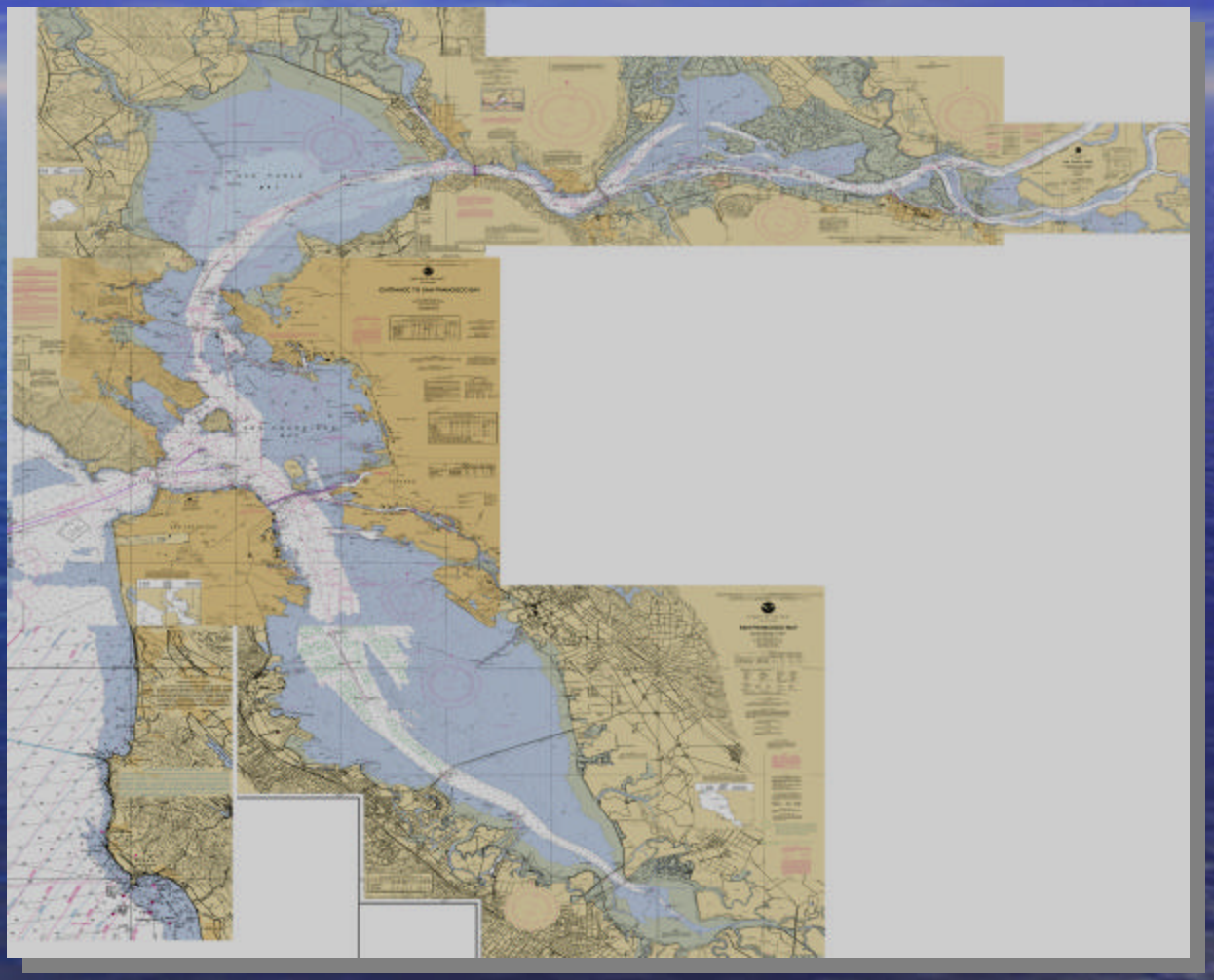
Building a Base Case Simulation

- We Need:
  - Map of the study area
  - Ferry schedules and Ferry Routes
  - Traffic data from the VTS
  - Vessel track data from the VTS
  - Environmental data – wind, visibility.
- We need:
  - Small vessel data – Regatta Events
    (Particularly their locations in lat long coordinates)

Building the Simulation (Modeling Traffic)

Map of the Study Area

- This map was creating by converting NOAA electronic charts to bitmap format and by connecting them together.



Current and Future Ferry Schedules

- Base Case = Year 2000 Ferry Schedules (collected from Ferry Operators
- Spreadsheets for Alternatives 1, 2 and 3 were supplied by URS Corporation

Alternative 3 - Enhanced (Existing) Water Transit System

						Per Trip		Per Day- Minutes		In Minutes		
								----------Weekdays ----------				
Corridor	Route	Vessel Type	Speed (Knots)	Headways Weekdays	Vessels	Sailing Time	Idle Time	Sailing Time	Idle Time	Deadhead Time	Weekday Trips	Weekday Service Hrs
Transbay	Vallejo - SF	350+	35	15	8	53.8	6.2	6459	741	40	120	128
	Alameda Point-Mission Bay-SF	149	25	15	4	28.8	1.2	3456	144	60	120	60
	Oakland - SF	149	25	15	4	24.0	6.0	2880	720	60	120	60
	Harbor Bay - SF	149	25	15	4	25.2	4.8	3024	576	60	120	60
	Subtotal Transbay Corridor				*20*							*308*
Golden Gate	Sausalito-San Francisco	149	25	30	2	20.4	9.6	1224	576	30	60	30
	Tiburon-San Francisco	149	25	30	2	20.4	9.6	1224	576	30	60	30
	Larkspur-San Francisco	350+	35	15	6	31.8	13.2	3812	1588	30	120	90
	Subtotal Golden Gate Corridor				*10*							*150*
GGNRA Service	Alcatraz	200	25	60	1	8.4	6.6	134	106	15	16	10
	Subtotal GGNRA Service				*1*							*10*
	TOTAL SYSTEM				**31**			**22,213**	**5,027**	**325**	**736**	**468**
DATE:	9-Apr-02											
	alternative 3~rev											

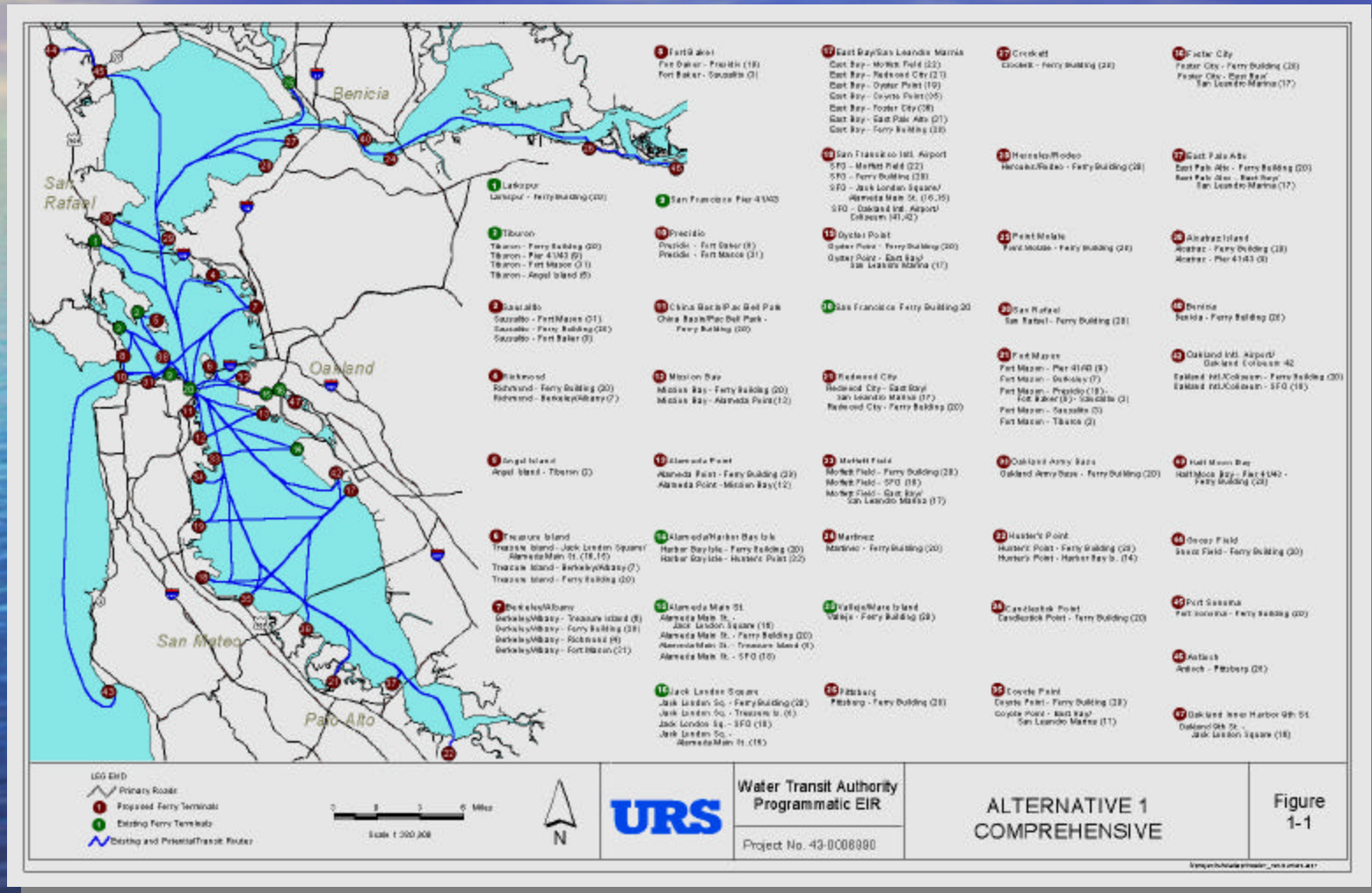
Ferry Schedules

- The spreadsheets were edited to match up with the routes in the simulation.

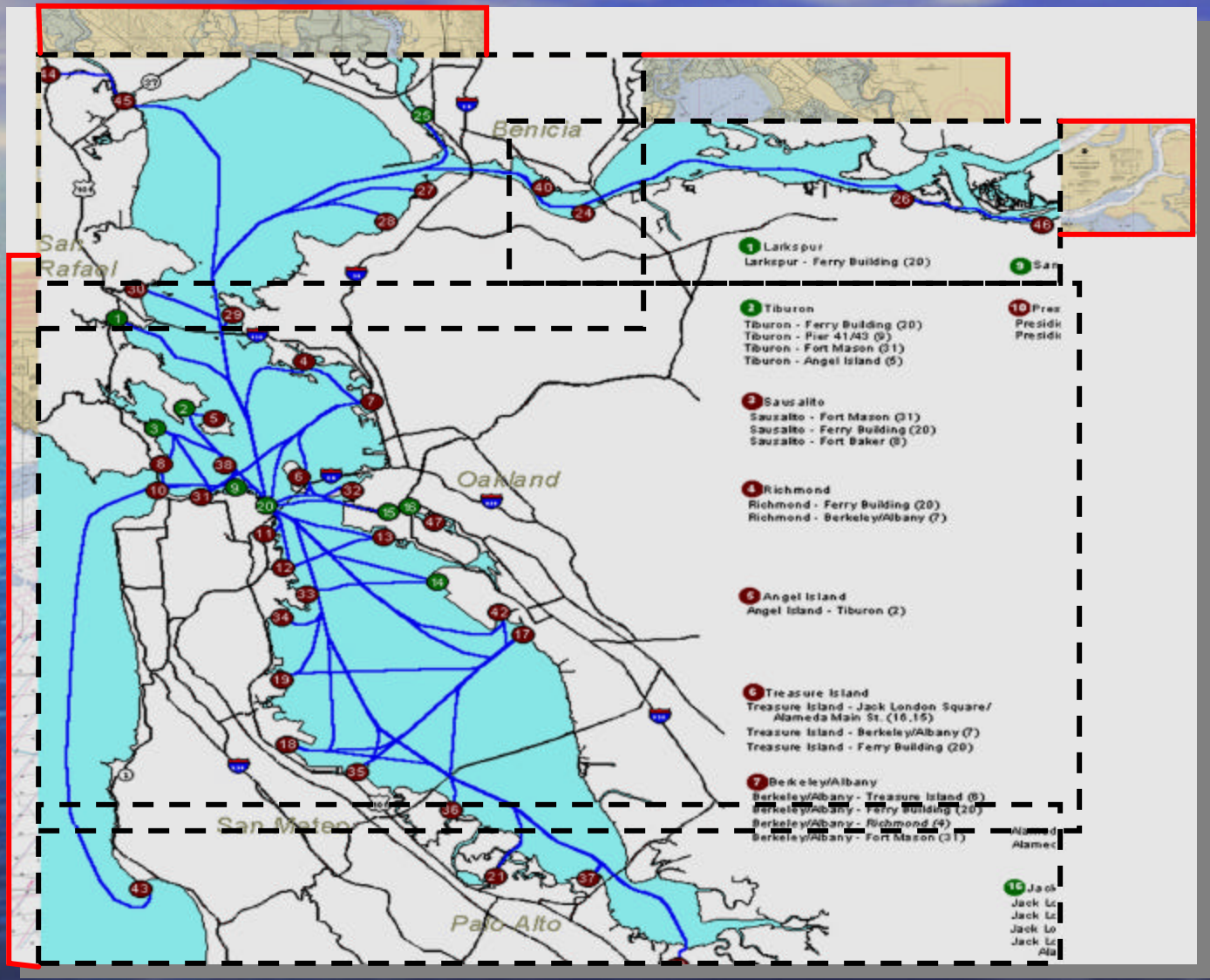
			Weekday	Weekend				Vessel
			Every	Every	From	To	Hours	Type
Route	From	To						
F28	Vallejo	Ferry Building	15	30	6:00	21:00	15	7
F7	Ferry Building	Pier 41	15	30	7:00	22:00	15	7
F21	Pier 41	Vallejo	15	30	6:20	21:20	15	7
A3	Alameda Point	Mission Bay	15	15	6:00	21:00	15	8
A37	Mission Bay	Alameda Point	15	30	6:00	21:00	15	8
F14	Oakland	Alameda	15	15	6:00	21:00	15	8
F1	Alameda	Ferry Building	15	15	6:10	21:10	15	8
F7	Ferry Building	Pier 41	15	15	6:30	21:30	15	8
F18	Pier 41	Ferry Building	15	15	6:00	21:00	15	8
F4	Ferry Building	Alameda	15	15	6:15	21:15	15	8
F2	Alameda	Oakland	15	15	6:35	21:35	15	8
F5	Ferry Building	Harbor Bay	15	30	6:00	21:00	15	8
F10	Harbor Bay	Ferry Building	15	30	6:00	21:00	15	8
F23	Sausalito	San Francisco	30	60	6:00	21:00	15	8
F25	San Francisco	Sausalito	30	60	6:00	21:00	15	8
F26	Tiburon	Ferry Building	30	60	6:00	21:00	15	8
F8	Ferry Building	Tiburon	30	60	6:00	21:00	15	8
F22	Larkspur	Ferry Building	15	30	6:00	21:00	15	7
F13	Ferry Building	Larkspur	15	30	6:00	21:00	15	7

- VBA programs were written to create arrivals databases suitable for the simulation program.

Ferry Routes Developed by URS Corporation



Piecing URS MAP on top of NOAA Collage



Other Large Maritime Traffic

- Detailed Vessel Arrival and Departure Data for Multiple Years from VTS San Francisco:
  - Vessel Class
  - Arrival Time into Study Area (Time, Day and Month)
  - Origin and Destination
  - Vessel Route (or Way Points)
- VTS Waypoints data
  - 2001 data was used as the primary source
  - Augmented by 2000 data
  - 99.5% of traffic could be matched to a waypoint defined route
  - Remaining 0.5% had missing departure and destination point information

Example of Vessel Routes (LPG Carriers)

- Routes like the one shown were created using way points data supplied by SF VTS

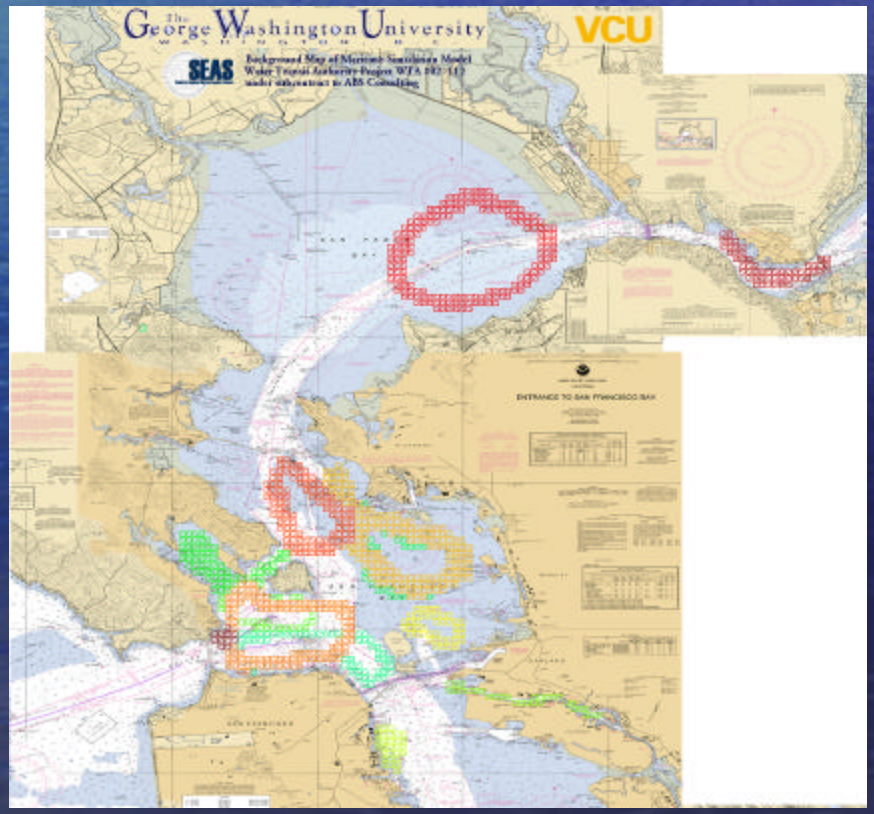
Regatta Events

- The USCG supplied their Marine Event List

EVENT NUMBER	EVENT	LOCATION	Sailing_Area	DATE	Start_Time	End_Time
SF-01-348	TYC BROTHERS-SISTERS	NORTH BAY #16	11	4-Jul-01	12:00	17:00
SF-01-406	TYC H.O. LIND #3-4	NORTH BAY/ #16	11	21-Jul-01	12:00	17:00
SF-01-678	TYC DOUBLE HANDED RACE	NORTH BAY/#16	11	13-Oct-01	12:00	17:00
SF-01-425	TYC BEHRENS #5-6	NORTH BAY/#16	11	28-Jul-01	12:00	17:00
SF-01-544	TYC BEHRENS #7-8	NORTH BAY/#16	11	25-Aug-01	12:00	17:00
SF-01-320	TYC H.O. LIND #2	NORTH BAY #16	11	23-Jun-01	13:00	17:00
SF-01-202	TYC H.O. LIND #1	NORTH BAY/ #16	11	19-May-01	13:00	17:00
SF-01-246	TYC FRIDAY NIGHT #3	NORTH BAY #16	11	1-Jun-01	18:00	21:00
SF-01-292	TYC FRIDAY NIGHT #4	NORTH BAY/ #16	11	15-Jun-01	18:00	21:00
SF-01-340	TYC FRIDAY NIGHT #5	NORTH BAY/ #16	11	29-Jun-01	18:00	21:00
SF-01-378	TYC FRIDAY NIGHT #6	NORTH BAY/ #16	11	13-Jul-01	18:00	21:00
SF-01-420	TYC FRIDAY NIGHT #7	NORTH BAY/ #16	11	27-Jul-01	18:00	21:00
SF-01-149	TYC FRIDAY NIGHT #1	NORTH BAY/#16	11	27-Apr-01	18:00	21:00
SF-01-470	TYC FRIDAY NIGHT #8	NORTH BAY/#16	11	10-Aug-01	18:00	21:00
SF-01-536	TYC FRIDAY #9	NORTH BAY/#16	11	24-Aug-01	18:00	21:00
SF-01-997	Bay Race	Benicia Yacht Club	13	27-Oct-01	9:00	11:00
SF-01-1011	Get Out the Vote	Pier One S.F.	1	3-Nov-01	10:00	11:00
SF-01-647	CYC TRITON NATIONALS	KNOX/ #6	5	28-Sep-01	11:00	13:00
SF-01-655	CYC TRITON NATIONALS	KNOX/ #6	5	29-Sep-01	11:00	13:00
SF-01-660	CYC TRITON NATIONALS	KNOX/ #6	5	30-Sep-01	11:00	13:00
SF-01-789	Opening Day on San Francisco Bay	Along Northern shore of San Francisco	1	29-Apr-01	10:00	14:00
SF-01-003	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	7-Jan-01	11:00	14:30
SF-01-017	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	21-Jan-01	11:00	14:30
SF-01-031	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	4-Feb-01	12:30	14:30
SF-01-047	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	18-Feb-01	12:30	14:30
SF-01-065	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	4-Mar-01	12:30	14:30

Regatta Events

- The areas were matched up with maps supplied by Lieutenant Black and Stacey Shonk.



Comparison WSF Simulation to SF Bay Simulation

- Washington State
  - 13 Ferry Routes
  - 100 Routes for other VTS Traffic
  - No Special Events

- San Francisco Bay
  - 18 Ferry Routes (Base). 68 Ferry routes (Alternative 1)
  - 6000 Routes for other VTS Traffic
  - 1000 Special Events

COMPLEXITY DIFFERS BY ORDER OF MAGNITUDE!

Kudos To SF VTS!

- Without their help, efficient and timely response to our repeated questions and data requests we would have been pulling our hair out.

Building the Simulation (Modeling Restricted Visibility)

Environmental Data

- Study Area has been divided into **five** separate zones to determine visibility pattern
- Divisions made based on differences in visibility pattern noted in the Coast Pilot and data availability
- Sea Visibility is generated using meteorological model utilizing Water Temp and Air Temp

Environmental Data - Wind

- Hourly Wind direction and Speed Data
  - Golden Gate 1/1998 – 12/2001
  - Port Chicago 1/1998 – 12/2001
  - Redwood City 1/1998 – 12/2001
  - Richmond 1/1998 – 12/2001
  - Alameda 1/1998 – 12/2001

Environmental Data

- San Francisco International Airport
  - Hourly Air Temperature 1990-1995
  - Hourly Land Visibility 1990-1995
  - Hourly Dew Point 1990-1995

Sea Visibility Model

W = Water Surface Temperatur e (Celsius)

D = Dewpoint Temperatur e (Celsius)

? = W - D

$$\text{Visibility} = \begin{cases} \text{Good}, & ? \leq 0°C \\ \text{Bad}, & ? > 0°C \end{cases}$$

Good = More than 0.6 miles

Bad = Less than 0.6 miles

Reference : Ray Sanderson, **Meteorology at Sea,** Stanford Maritime Limited, 1982

Environmental Data - VISIBILITY

- Hourly Air and Water Temperature Data
  - Golden Gate 1/1998 – 12/2001
  - Port Chicago 1/1998 – 12/2001
  - Redwood City 1/1998 – 12/2001
  - Richmond 1/1998 – 12/2001
  - Alameda 1/1998 – 12/2001

HOURLY DEW POINT DATA IS NOT AVAILABLE FOR THIS TIME PERIOD AND FOR THESE LOCATIONS!

Calculation of Dew Point Temp.

- Used SFO Dew Point Data:

  6 year averages of Dew points were calculated over the period from 1990-1995 per month and by an air temperature range of two degrees. These averages were used to convert 1998-2001 air temperature data to dew point data.

- **For example:** Average dew point for August was 13 in 1990-1995 when air temperature was between 14-16 degrees Celsius. An air temperature in August 1998 of 15 degrees would therefore be converted to a dew point of 13.

Visibility Model - Calibration

- To ensure the model more closely reflects restricted visibility conditions (mariners are required to use their fog signals) a calibration constant was be added for each month and location

$$\text{Visibility} = \begin{cases} \text{Good}, & ? \leq k^{\circ}C \\ \text{Bad}, & ? > k^{\circ}C \end{cases}$$

Calibrate to Sample Coast Pilot Data

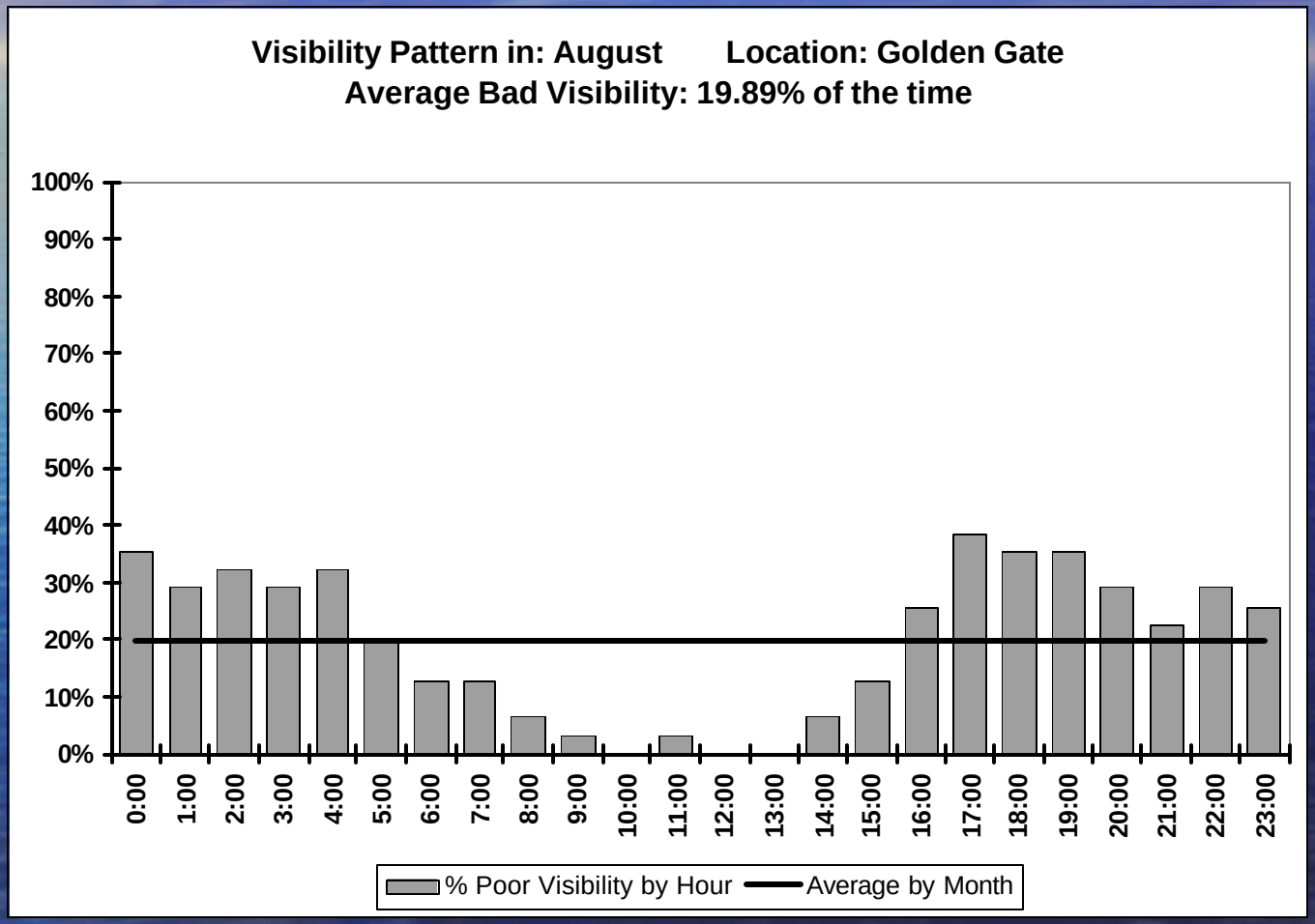
Location Golden Gate:

- August: Fog signals operate 15-20% of the time in Golden Gate
- March and April, fog signals operate about 7-10% of the time.

WHAT ABOUT THE OTHER MONTHS?

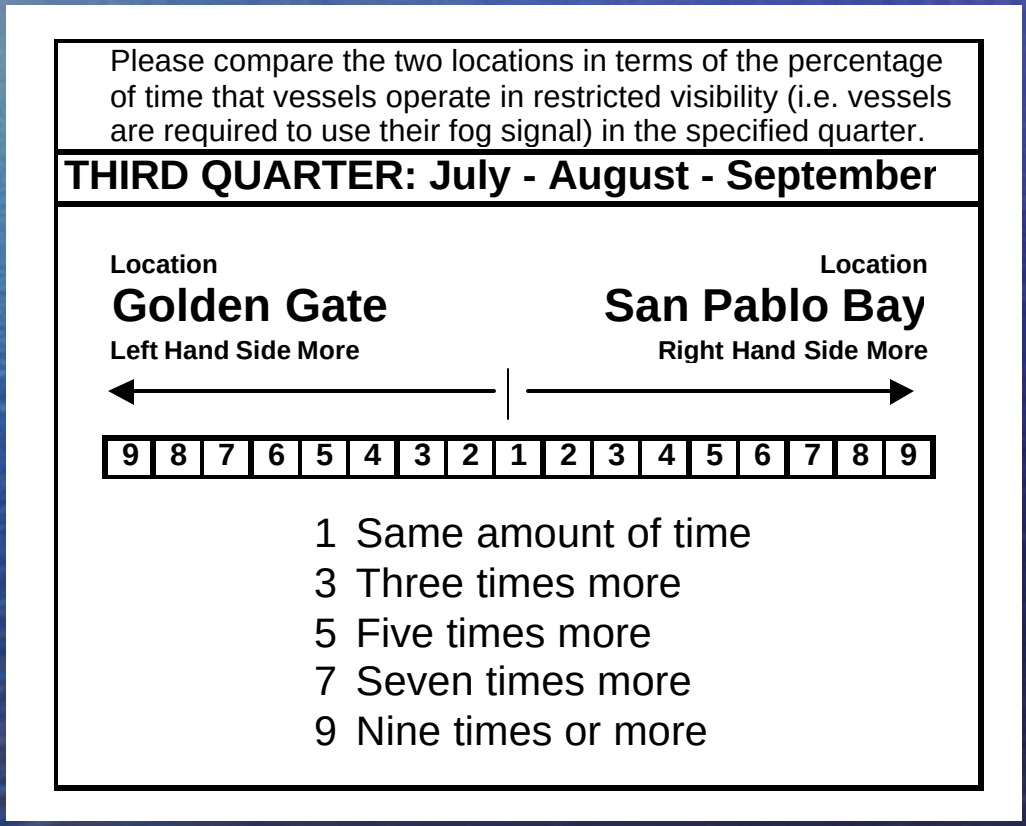
WHAT ABOUT THE OTHER LOCATIONS?

Visibility Model Results



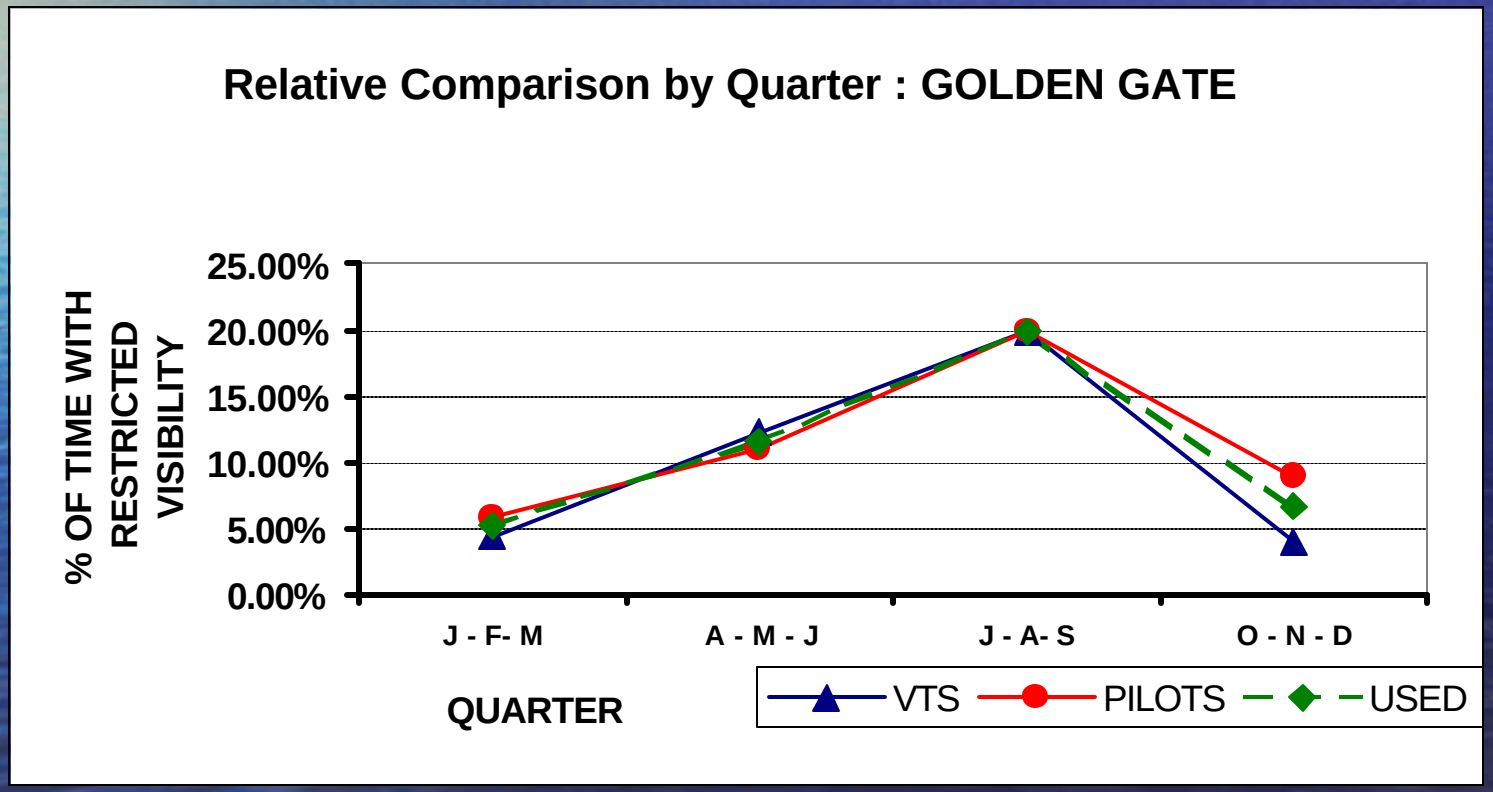
Visibility Model

- To calibrate the percentage of times restricted visibility conditions occur within each location information from the Coast Pilot 2000 was combined with expert judgment elicited using the Analytical Hierarchy Process technique.



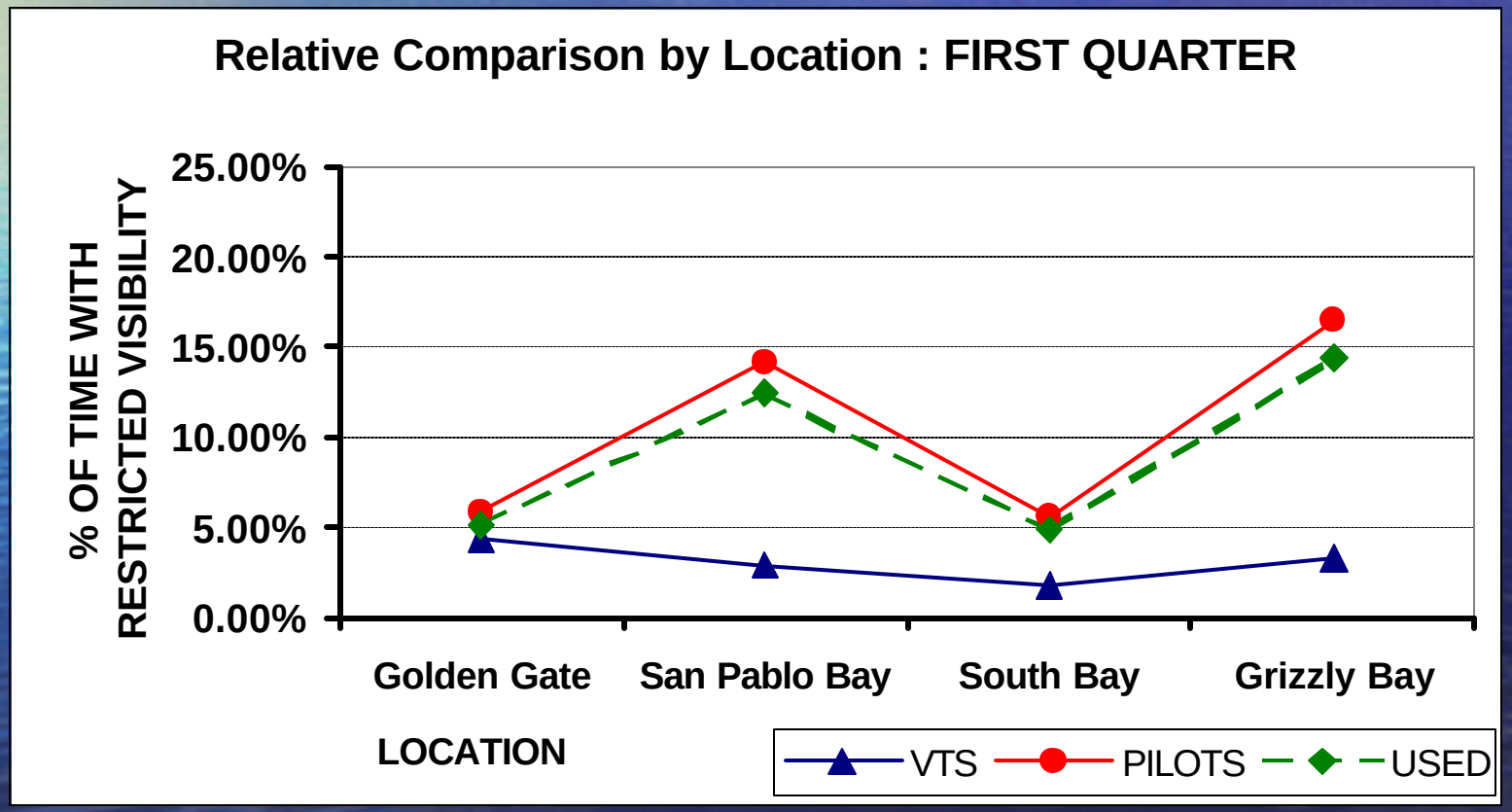
Visibility Model

- There was remarkable agreement between the VTS Operators and the SF Bar Pilots regarding visibility conditions at Golden Gate.



Visibility Model

- There was some level of disagreement regarding visibility conditions in the first quarter of the year.

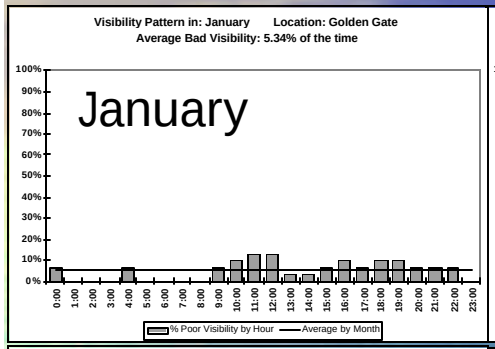


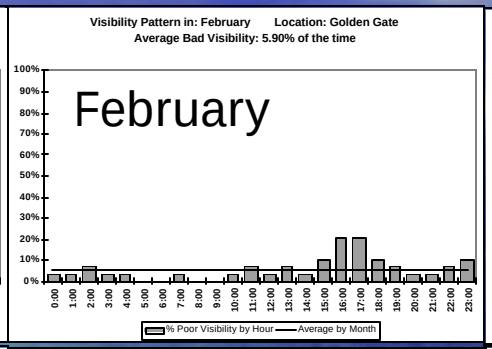
Visibility Model

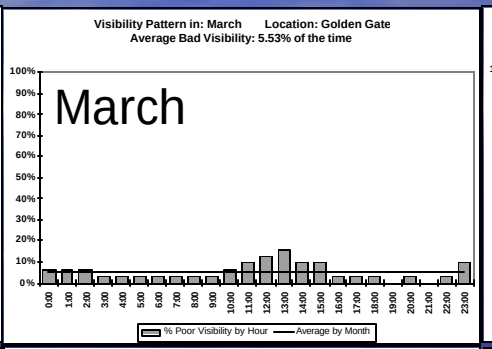
- Estimated Percentages of Time that Restricted Visibility Occurs by Quarter and by Location

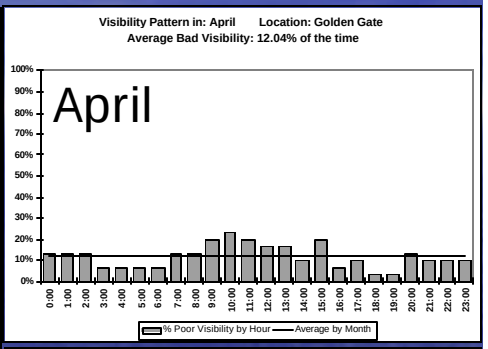
	First Quarter J - F- M	Second Quarter A - M - J	Third Quarter J - A- S	Fourth Quarter O - N - D
Golden Gate	5.17%	11.66%	20.00%	6.69%
San Pablo Bay	12.38%	6.17%	6.30%	9.62%
Alameda	7.49%	7.61%	10.61%	7.02%
South Bay	4.92%	5.00%	5.53%	4.74%
Grizzly Bay	14.40%	5.17%	5.34%	11.06%

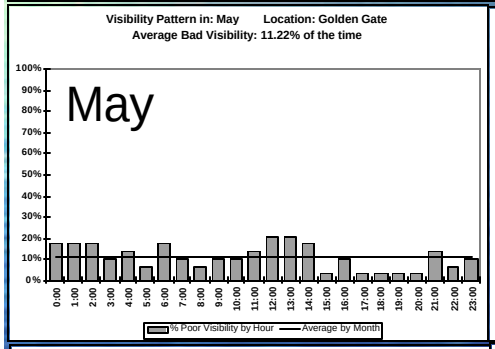
Visibility Model Results – GOLDEN GATE 2000

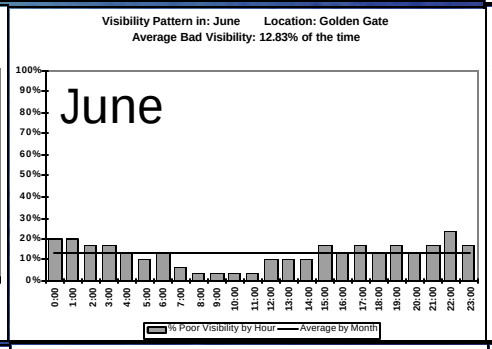


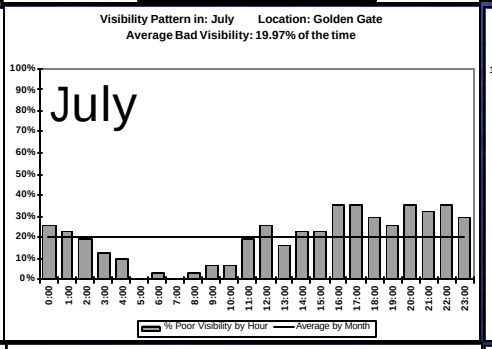


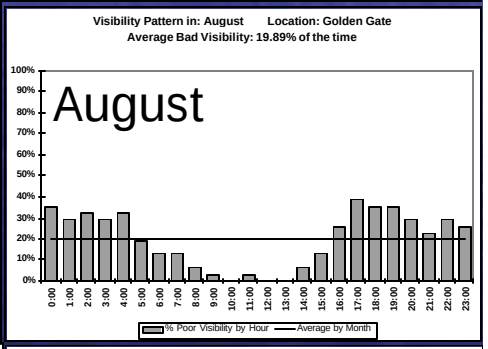


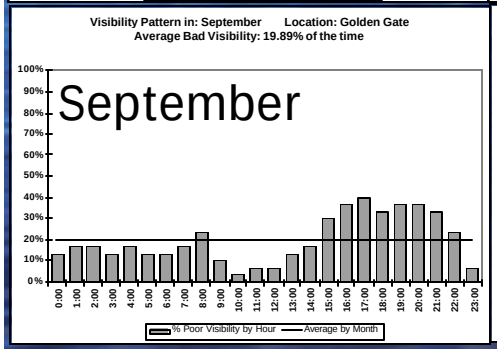


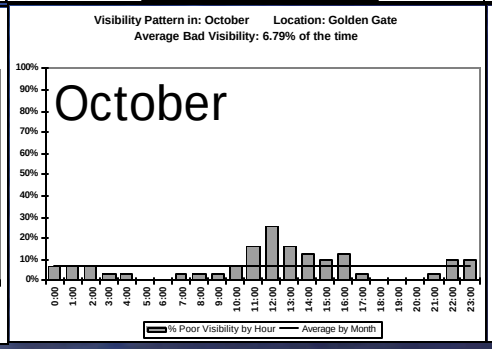


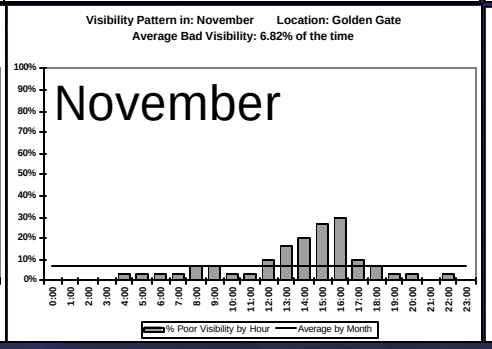


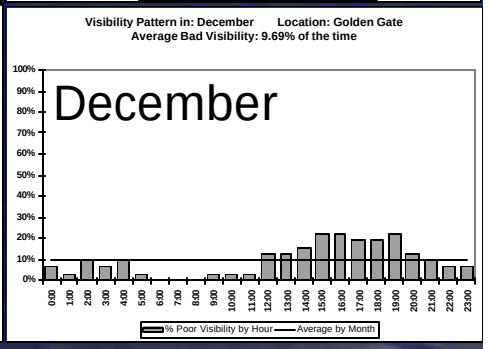




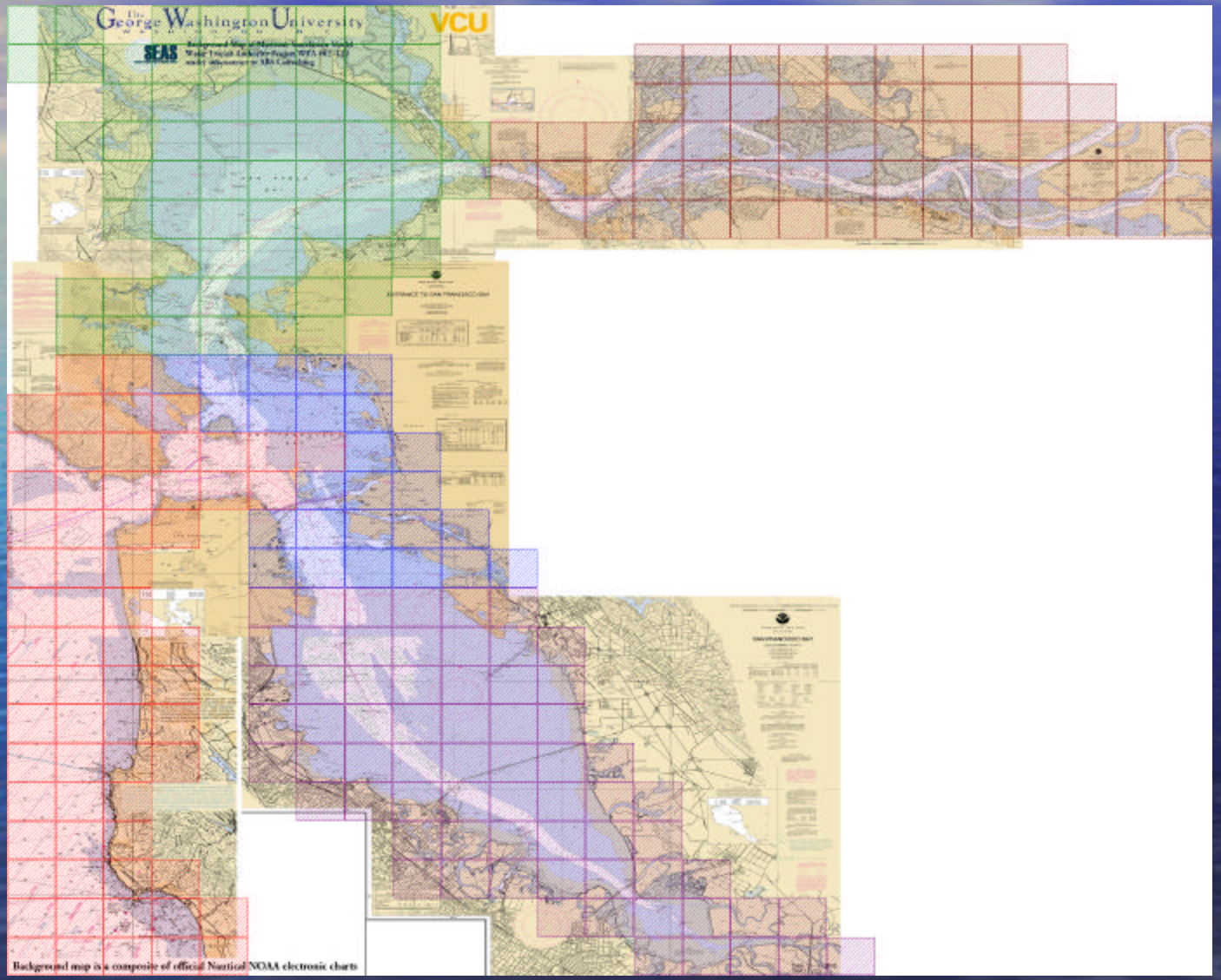






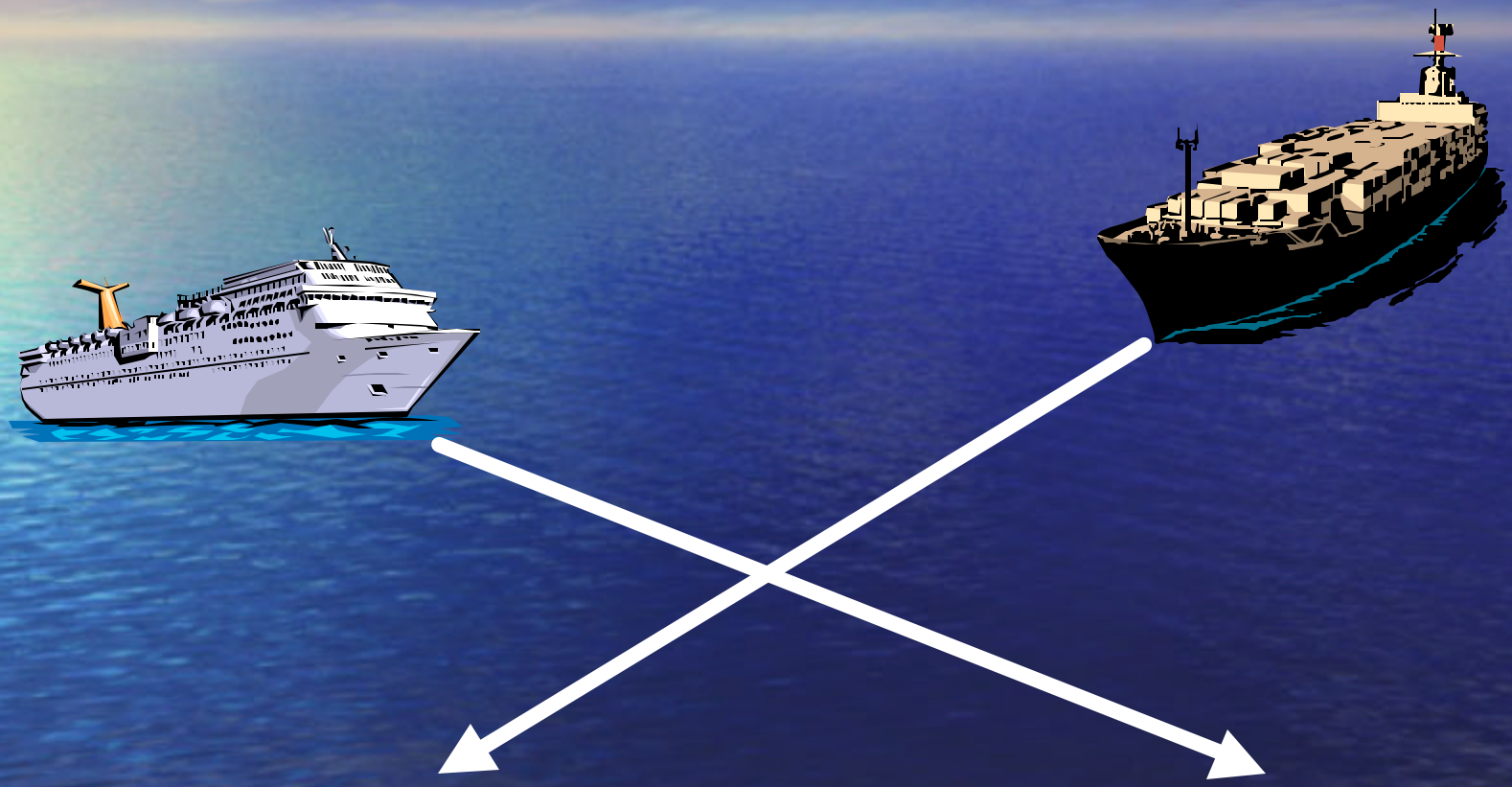


Locations in Visibility Model

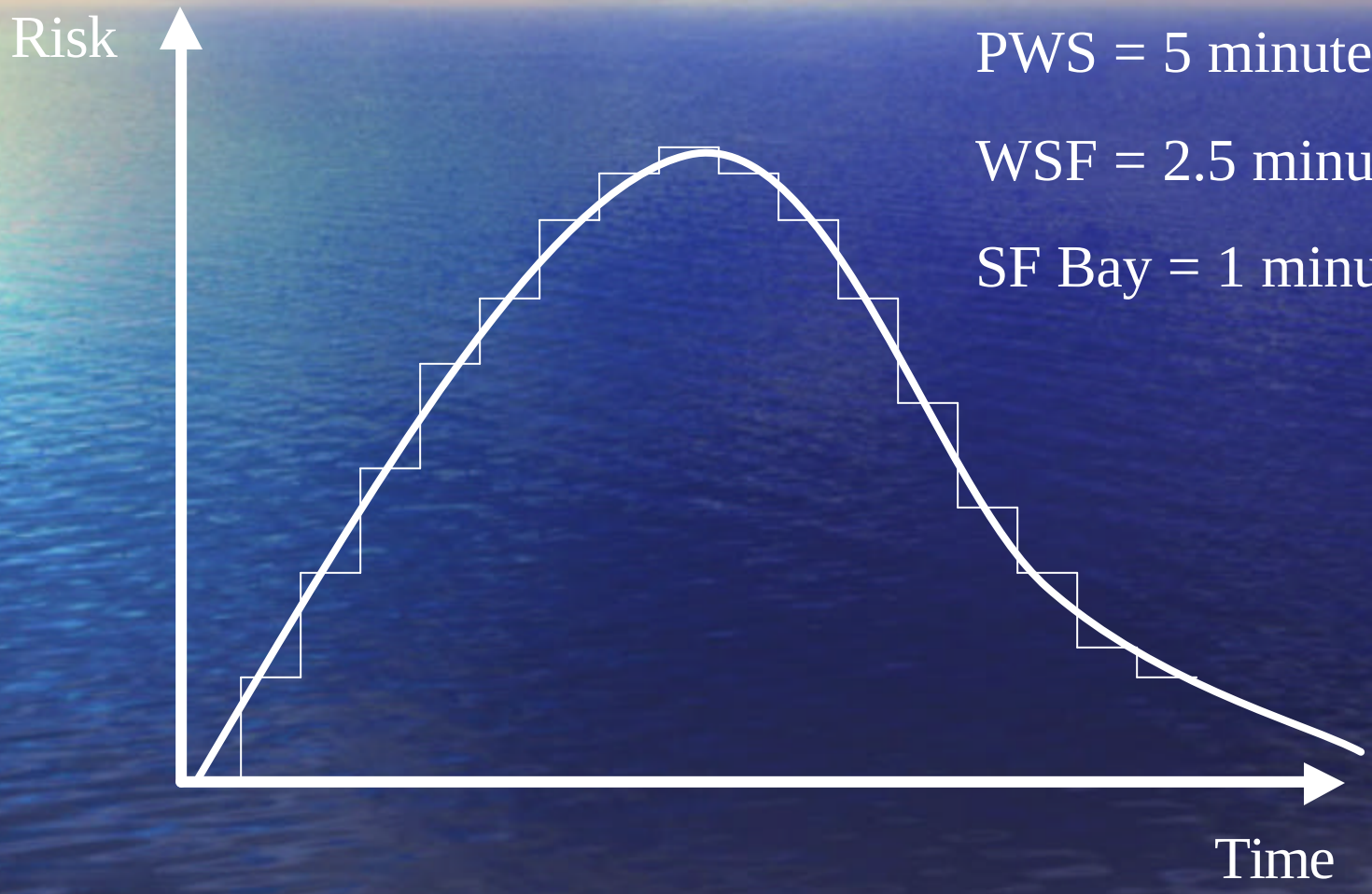


Building the Simulation (Counting Interactions)

Interacting Vessels



Risk During Interactions

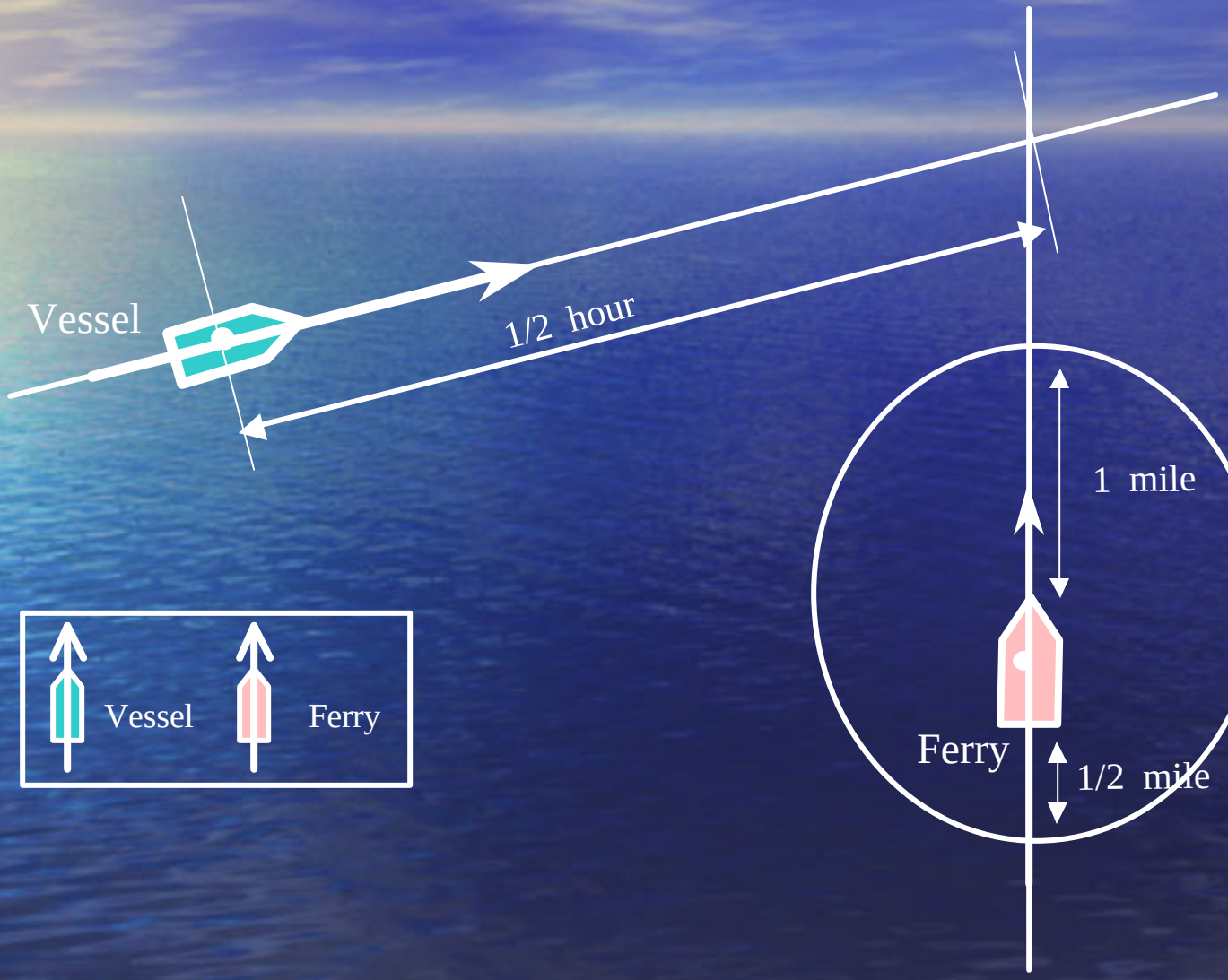


PWS = 5 minutes

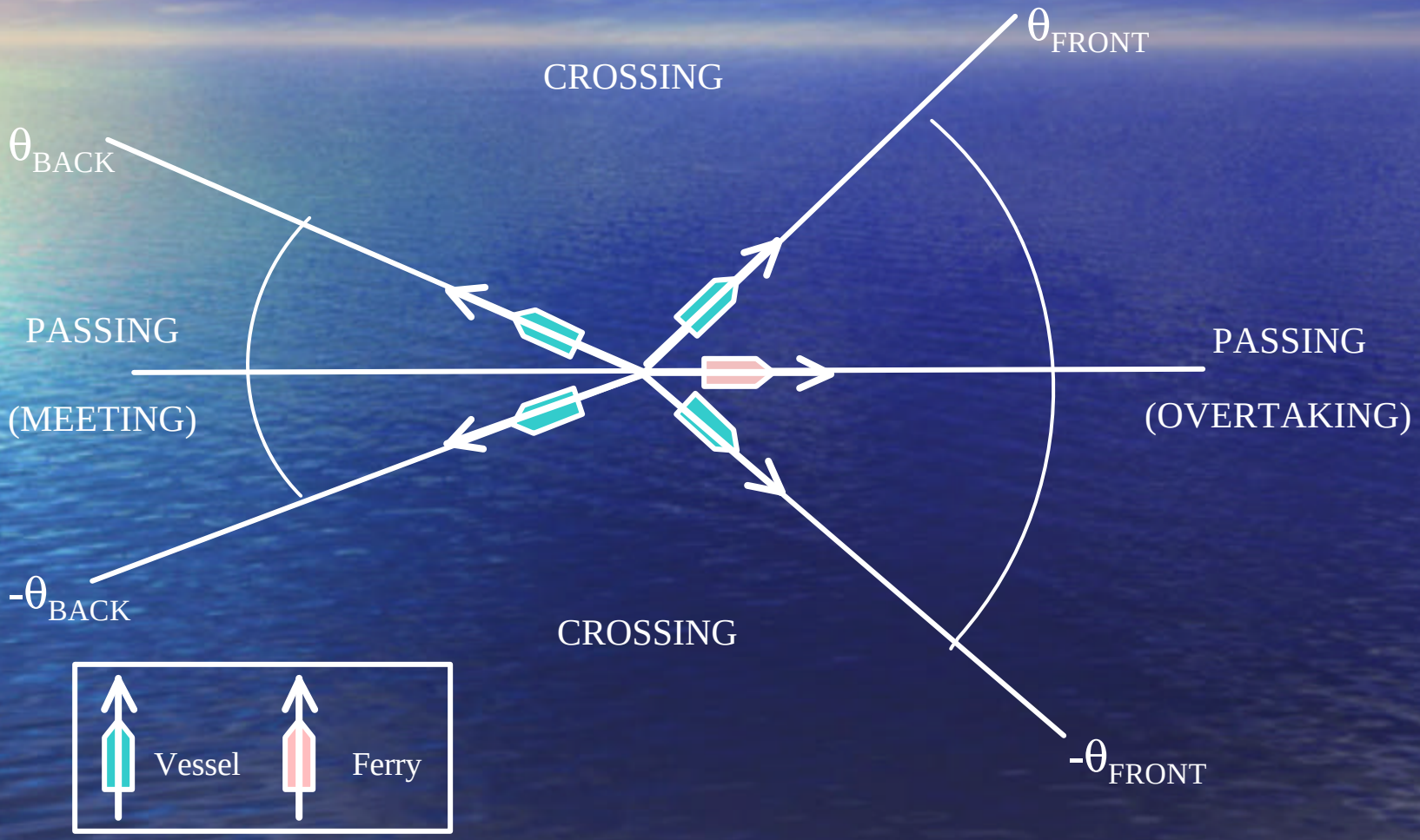
WSF = 2.5 minutes

SF Bay = 1 minute

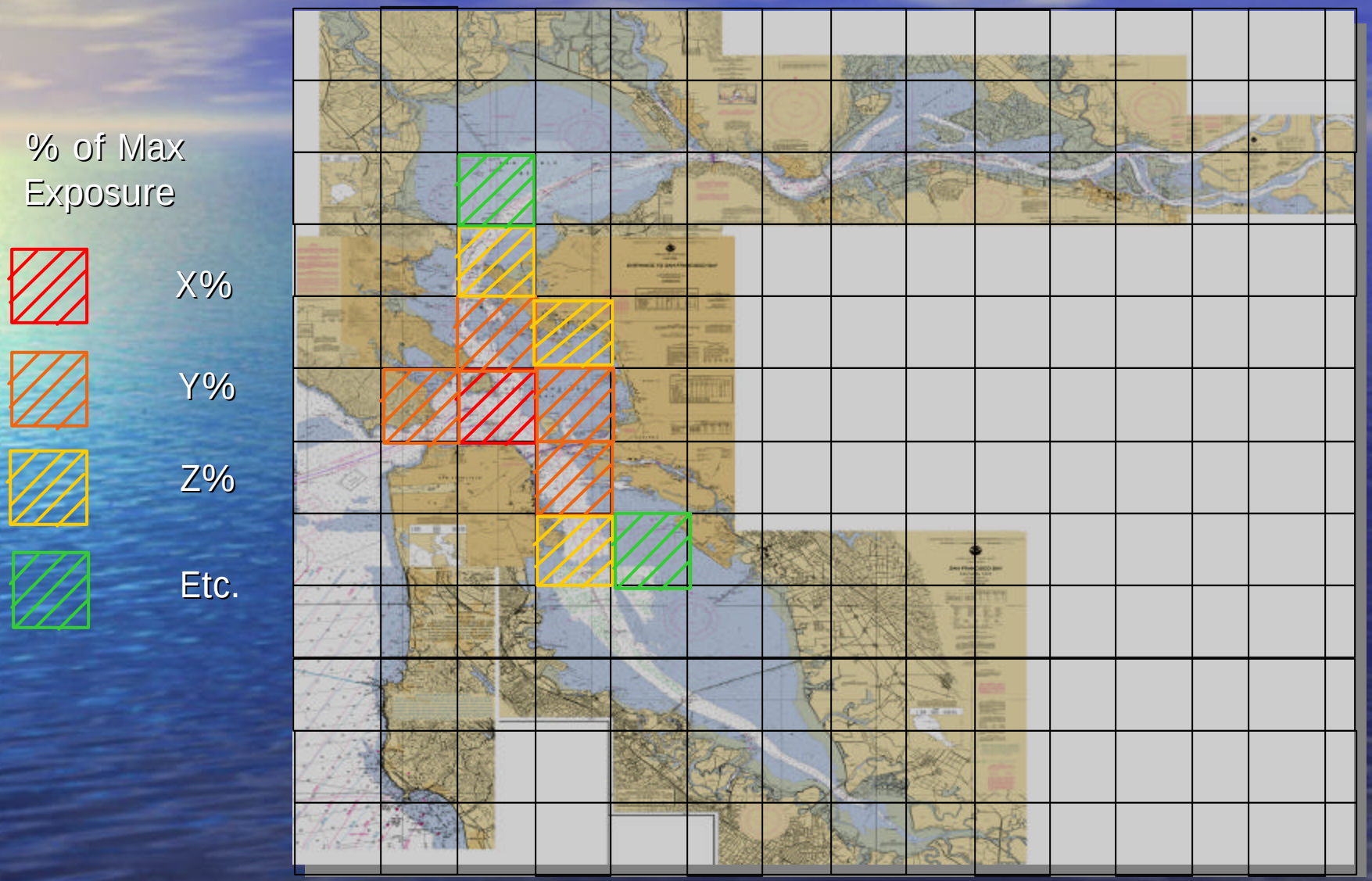
Simulation Counting - Crossing



Simulation Counting - < 1/2 Mile



Format of Output Results

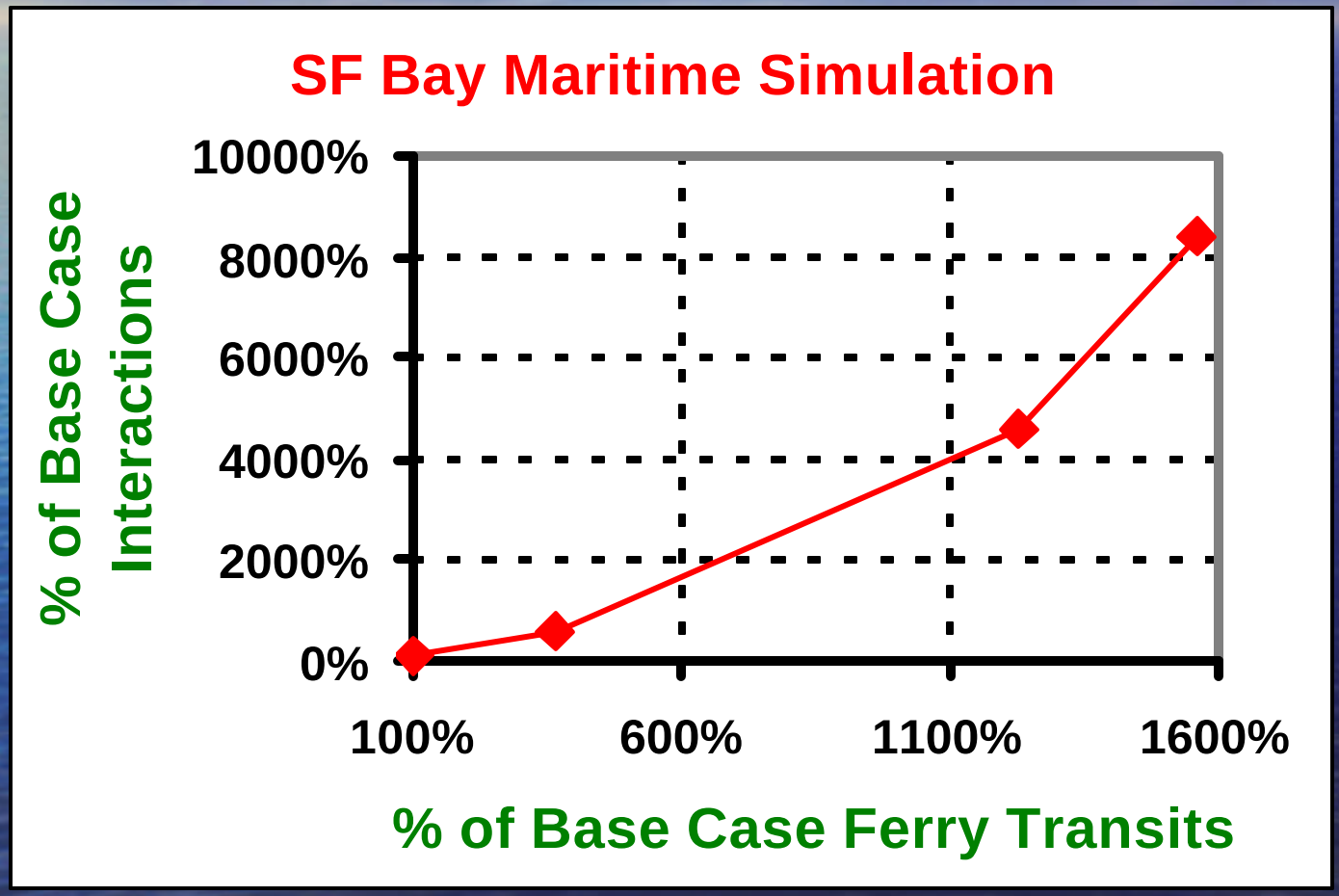


Simulation Analysis Results (Base Case, Alternative 1,2,3)

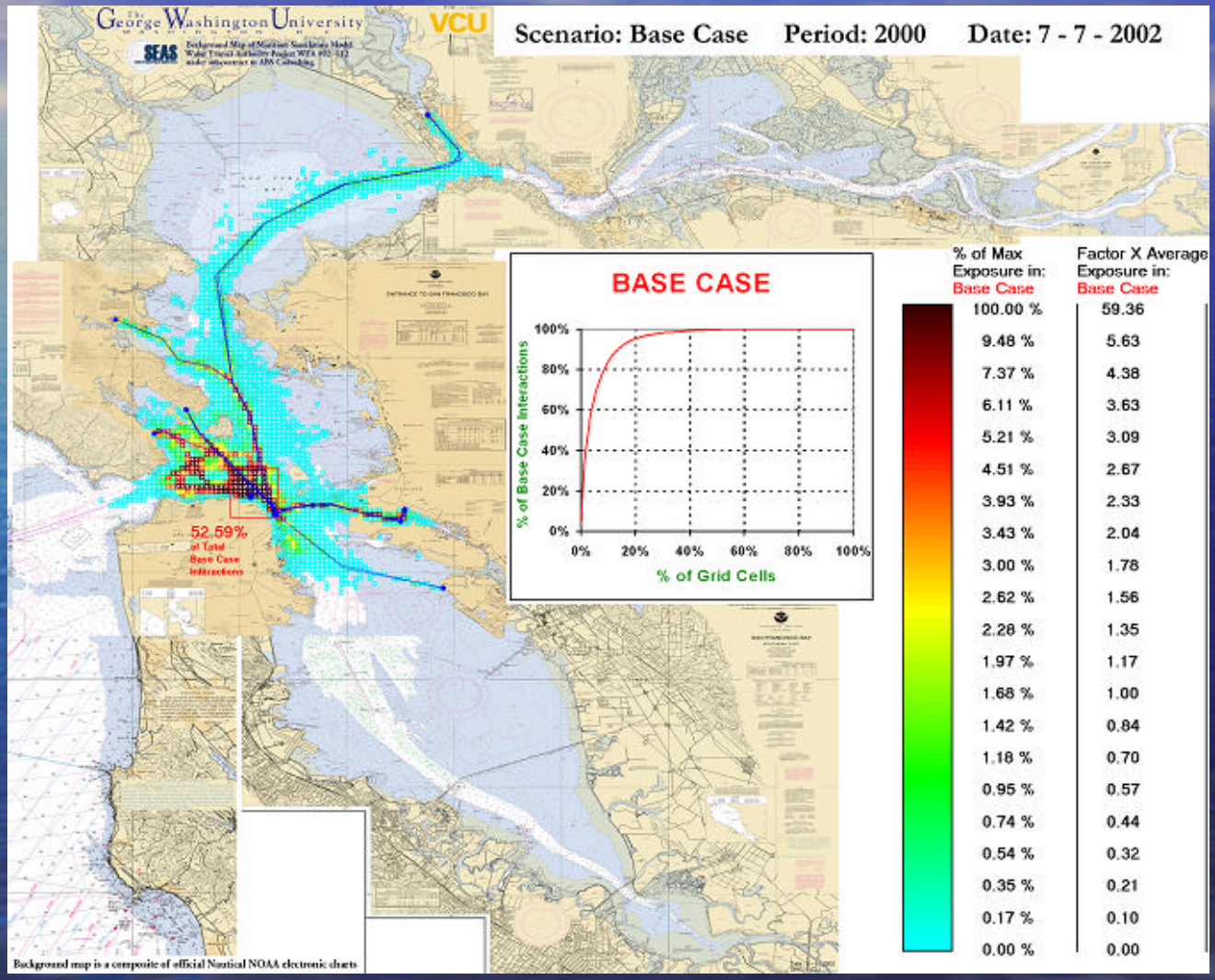
Overall Comparisons

	# Ferry Transits	# Grid Cells Covered	# Interactions	% Base Case Interactions in 20% of Cells
Base Case	100%	100%	100%	97%
Alternative 3	365%	116%	624%	600%
Alternative 2	1228%	233%	4620%	4500%
Alternative 1	1559%	240%	8359%	8200%

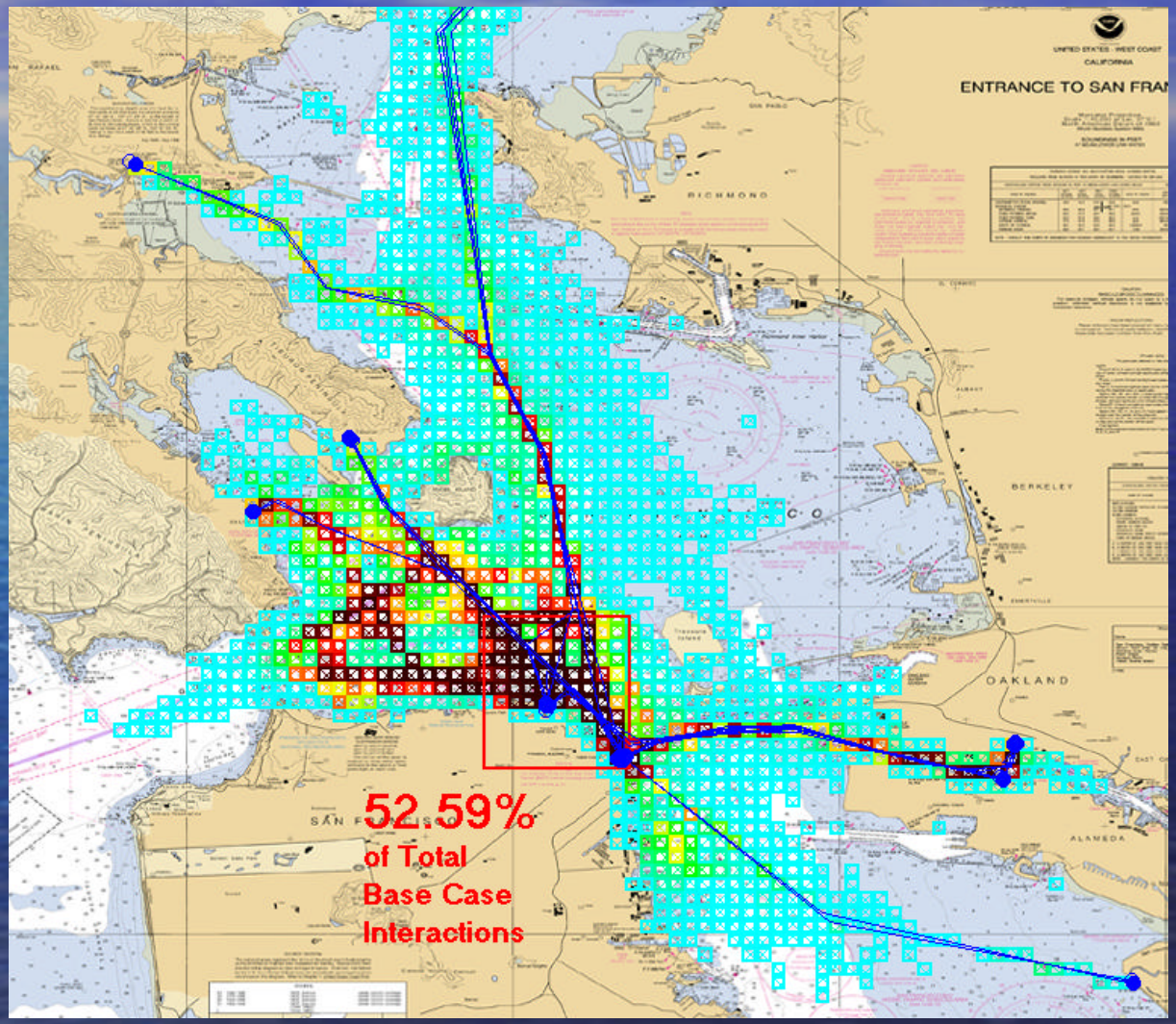
Transits vs. # Interactions



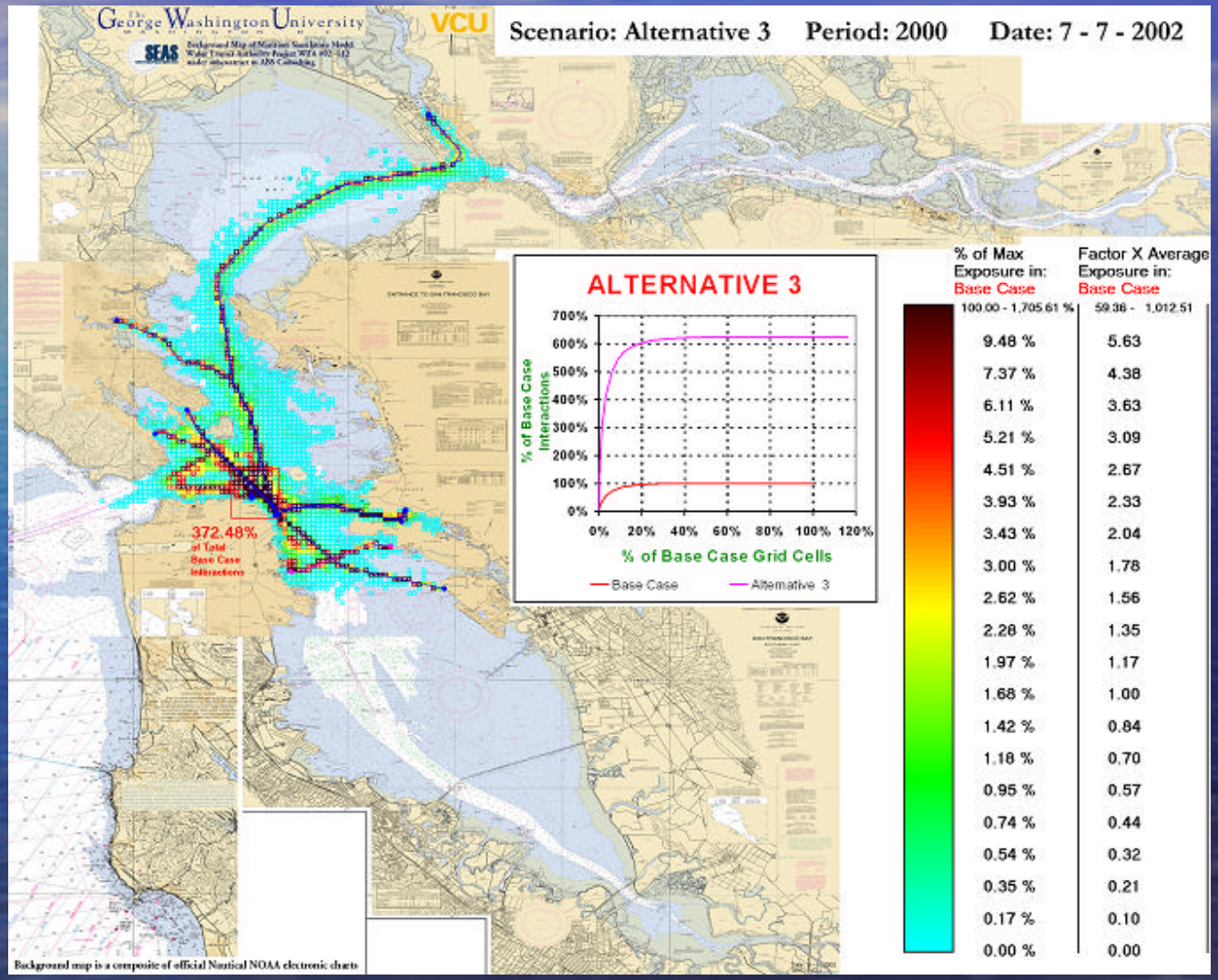
Base Case



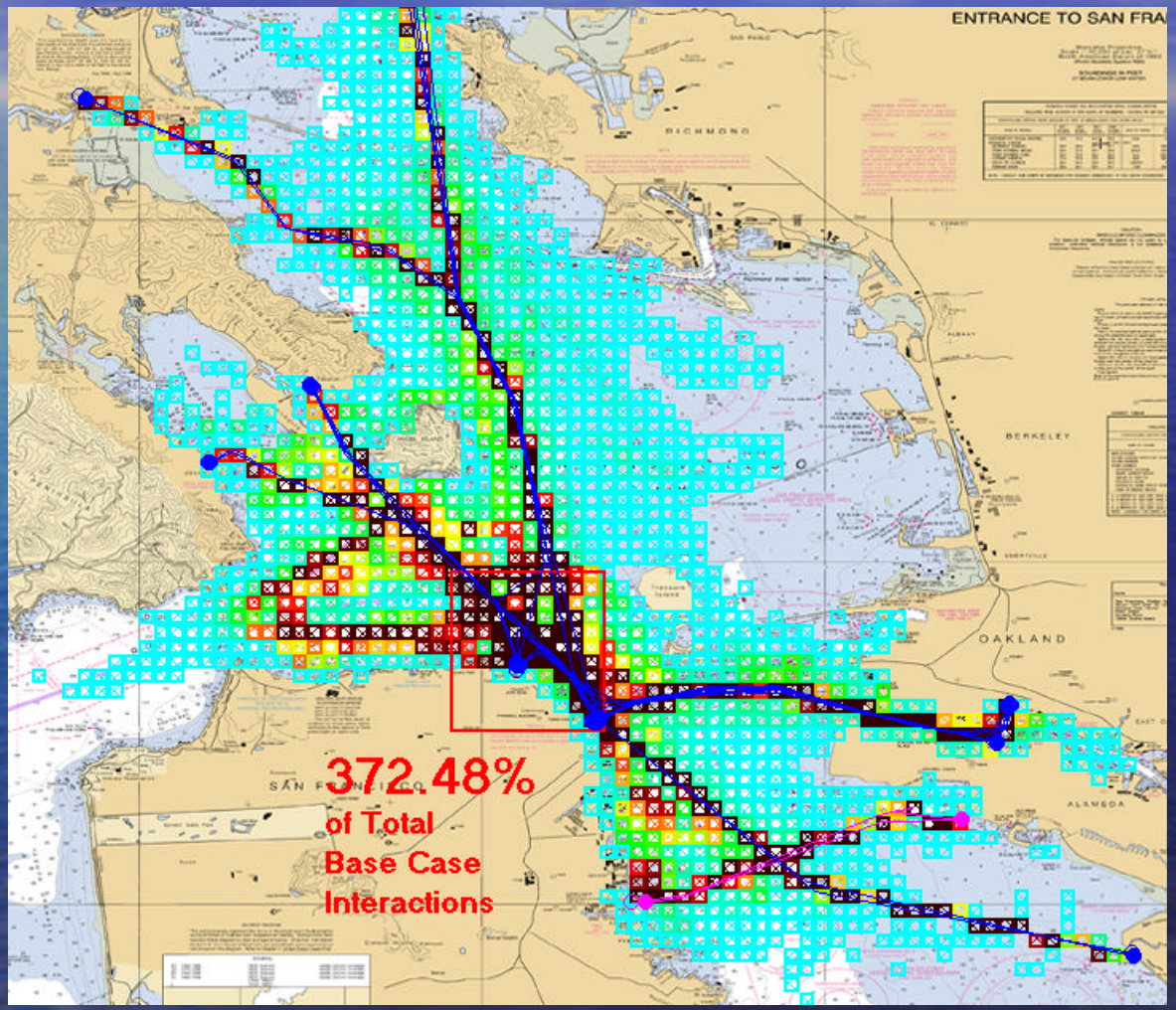
Base Case



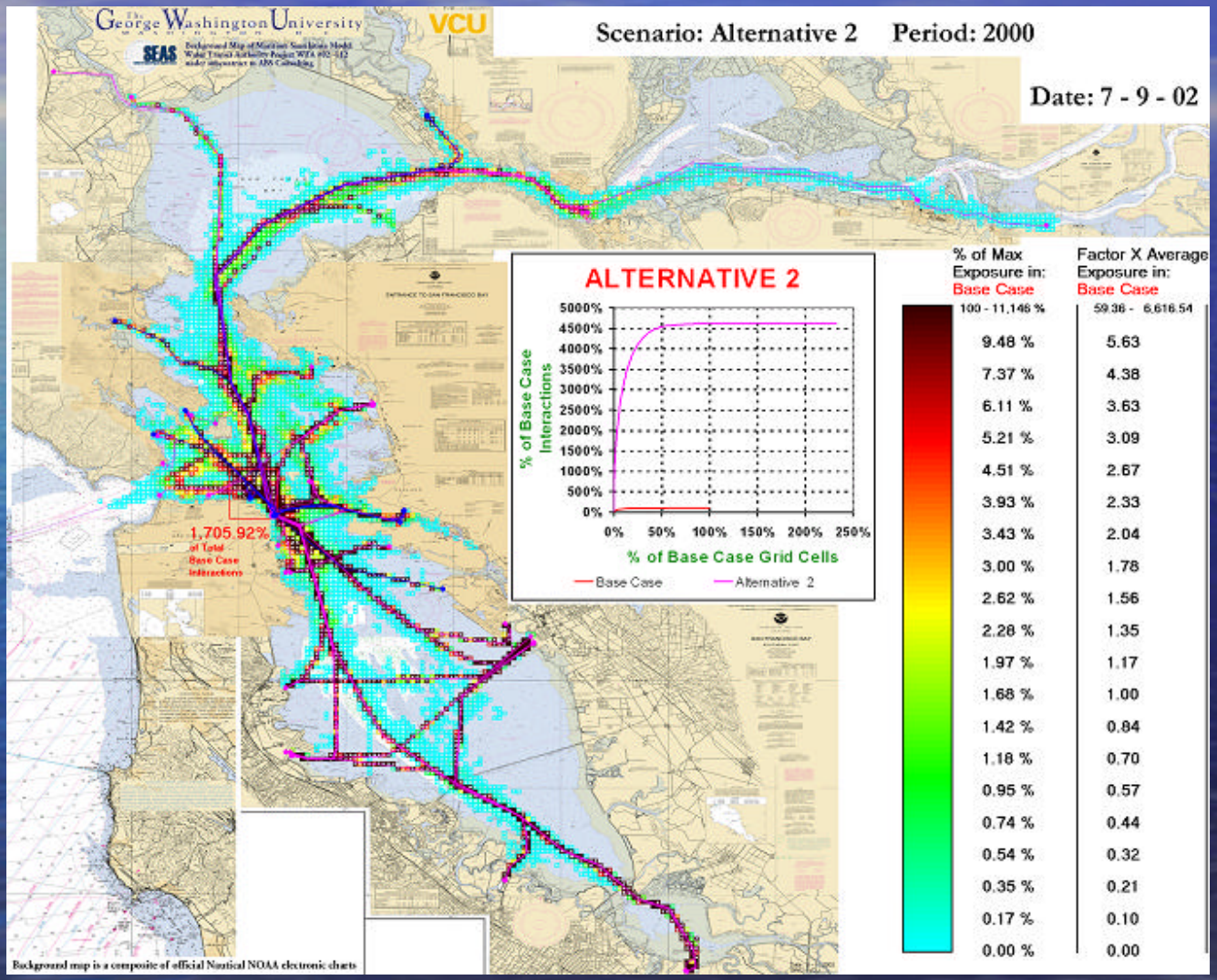
Alternative 3



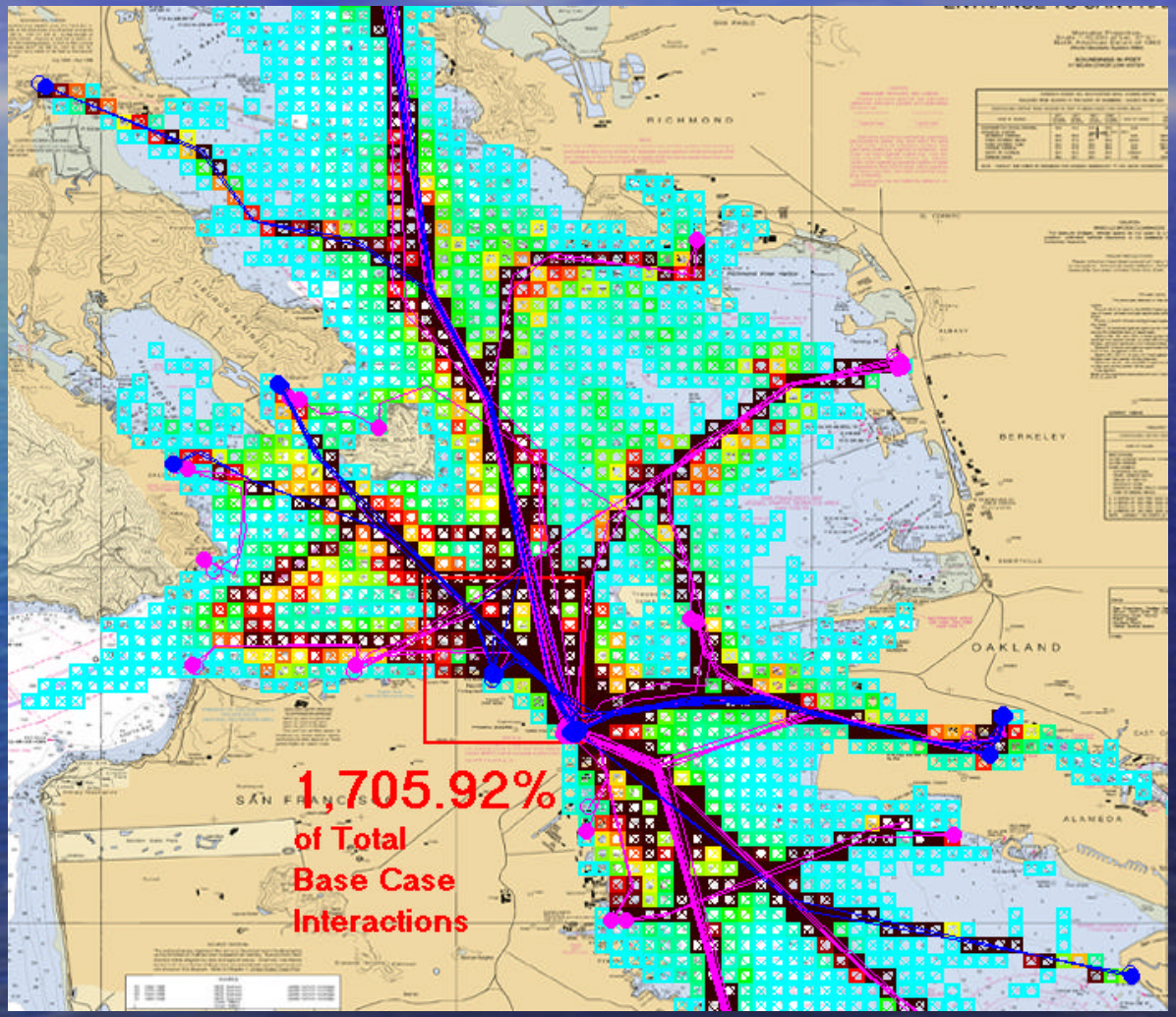
Alternative 3



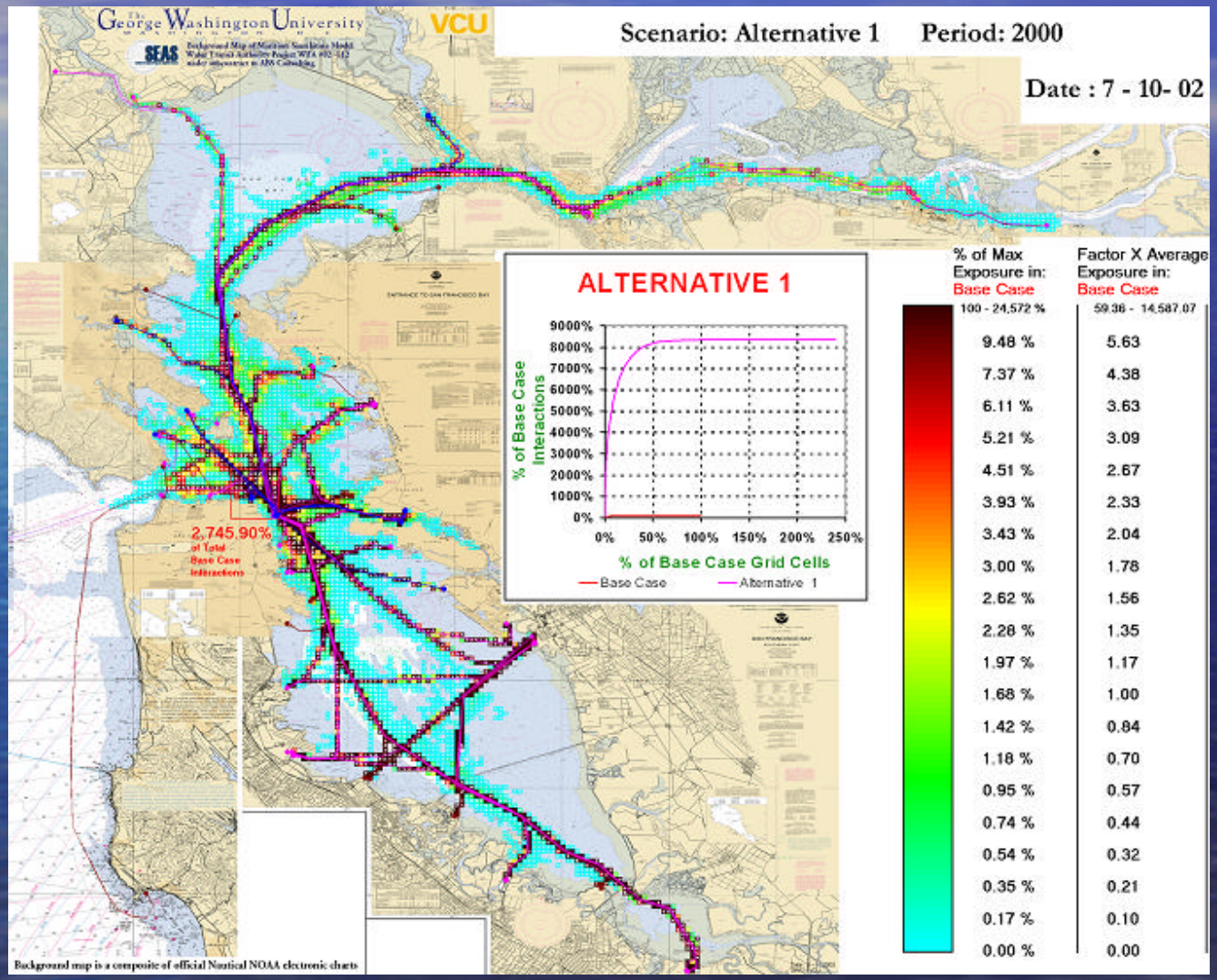
Alternative 2



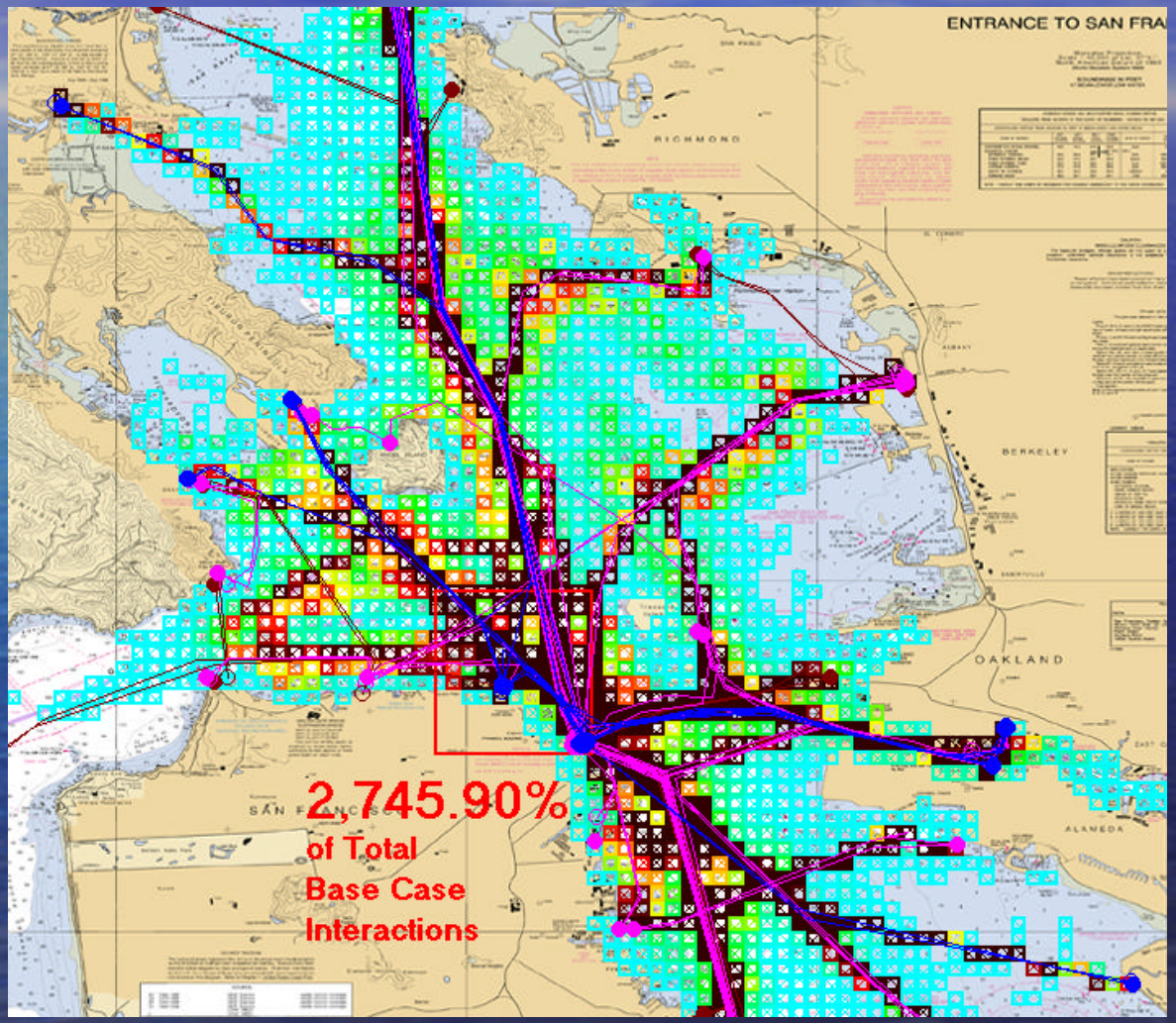
Alternative 2



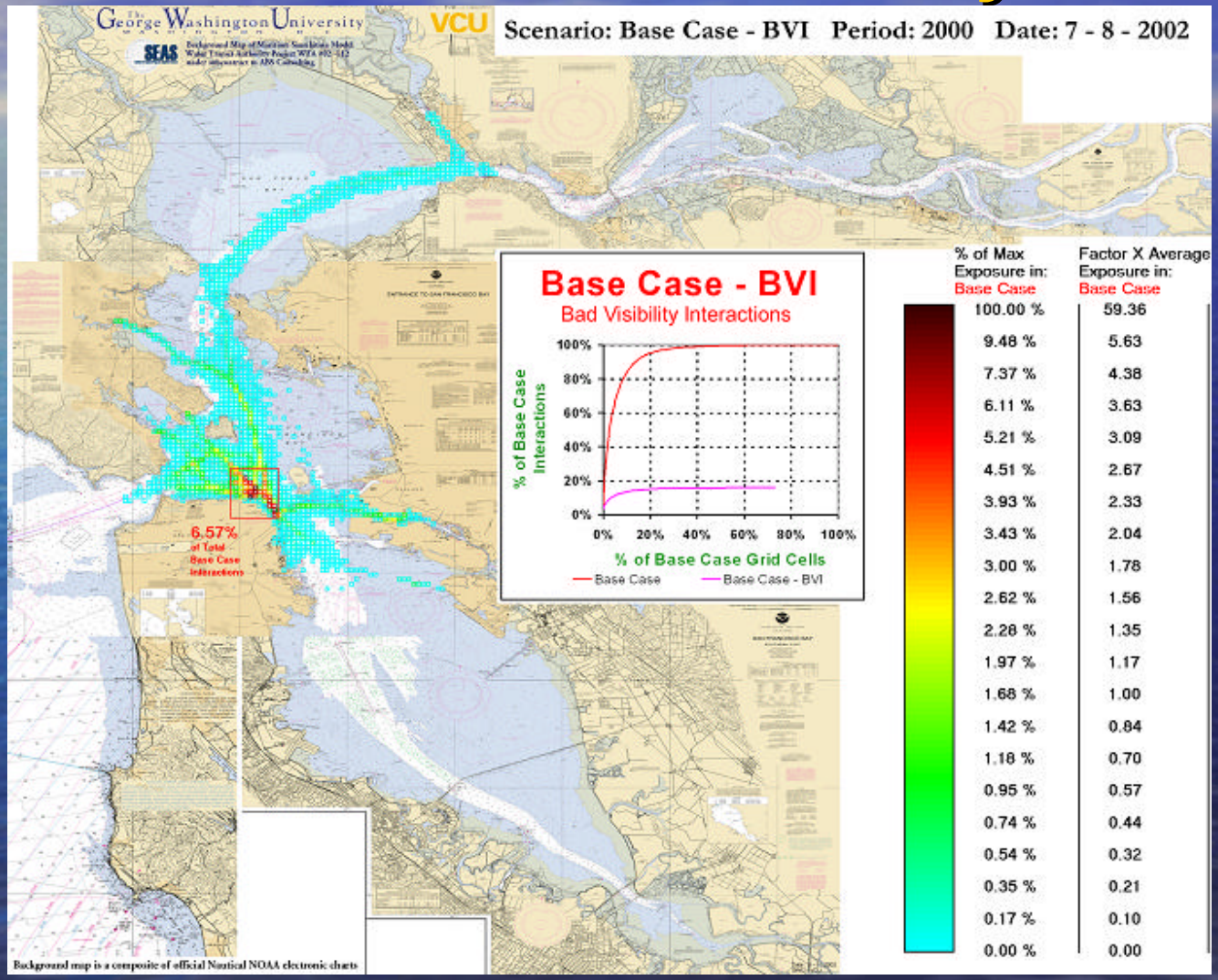
Alternative 1



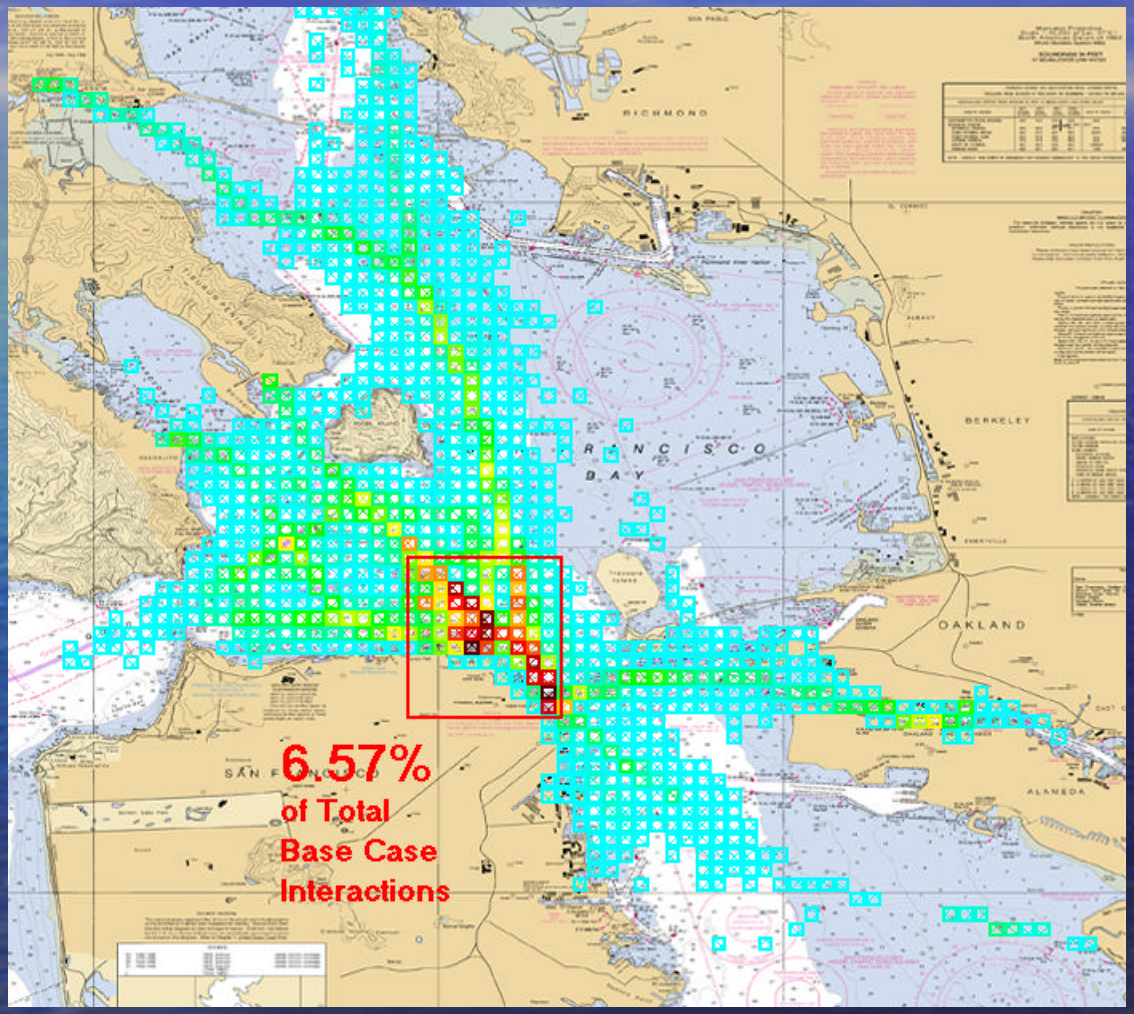
Alternative 1



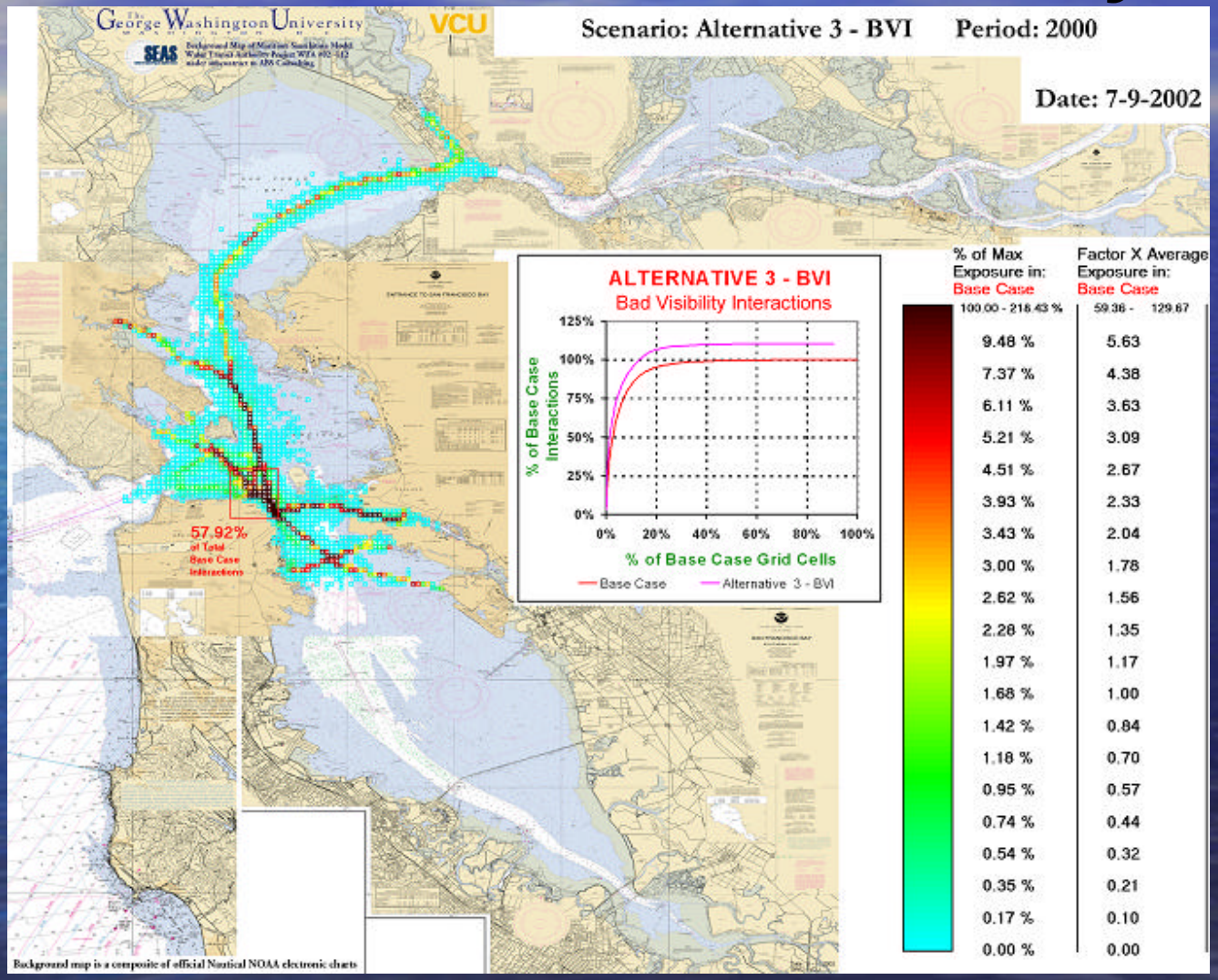
Base Case in Bad Visibility



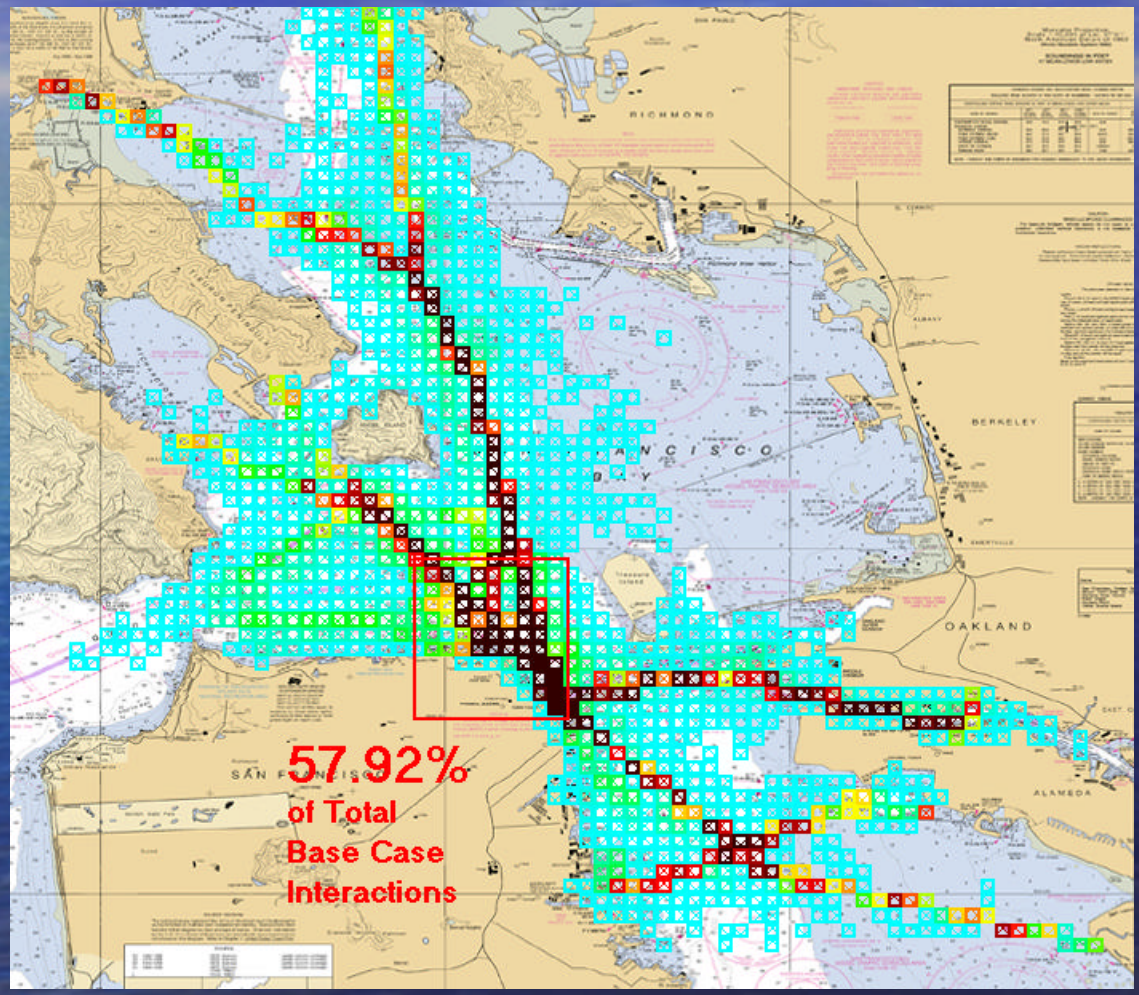
Base Case in Bad Visibility



Alternative 3 in Bad Visibility



Alternative 3 in Bad Visibility



Comparisons: Restricted Visibility

	# Ferry Transits	# Grid Cells Covered	# Interactions	% Base Case Interactions in Red Square
Base Case	100%	100%	100%	53%
Base Case - BVI		73%	16%	6.6%
Alternative 3	365%	116%	624%	372%
Alternative 3 - BVI		91%	110%	58%

6.2 X

7.0 X

6.9 X

8.8

Conclusion

The results seem to indicate that the safety levels currently enjoyed by the SF Bay ferry service cannot be maintained under the planned expansion scenarios without equally aggressive investment in risk intervention.

Recommendations

- Conduct Probabilistic Risk Assessment of SF Bay Ferry Service (i.e. analyze accident risk, not just interactions)
- Consider the Ferry Service as an Maritime Transportation System, not an individual collection of Ferry Routes
  a. Design a Ferry Route System (using traffic separation)
  b. Design a Ferry Schedules that distribute the arrivals and departures at major terminals
- Develop additional risk intervention measures that reduce the accident probability on a per interaction basis
- Test the effectiveness of these measures using the Maritime Extended Simulation Risk Model

Maritime Risk Assessment Links

- Maritime Risk Assessment Links
  - http://www.seas.gwu.edu/~dorpjr
  - http://www.people.vcu.edu/~jrmerric
- Available for downloading
  - Journal Papers, Proceedings, Reports
  - SF Bay Simulation Movies

QUESTIONS?