

Four Hours or Twenty Minutes: Write a Tsunami Warning Procedure

Investigation question: Using earthquake data, deep-ocean sensor readings and the rule that tsunami speed depends on water depth, what step-by-step procedure should a coastal warning office follow so that its harbor town gets enough time to evacuate without crying wolf?

Data-driven decision

Groups of 4

1 session

Setup 5 · Activity 48 · Cleanup 2 min

MS-ESS3-2 · assesses

MS-ETS1-2 · practice

MS-ETS1-3 · practice

Scientific purpose

Groups act as the warning office for Port Alder, an imagined harbor town on a Pacific coast loosely modeled on California's North Coast. They calculate how long tsunamis from three source zones take to reach the town by dividing each stretch of the path by the speed for its depth, and when the waves will pass two DART stations. They analyze a record of twelve past earthquakes to find which data predict a dangerous wave and derive a rule that turns a DART reading into a forecast height. Then they write a procedure of if-then steps, test it event by event against the record, count misses, false alarms and late warnings, and merge the best steps of their procedure with another group's.

Why this helps students with this chapter

Students tend to think a warning system either 'predicts' a tsunami or fails. Working the numbers shows what warning centers really do: forecast an arrival time from distance and depth once a quake has happened, and confirm the size with deep-ocean sensors before deciding how far to go. The record forces trade-offs. A rule based on magnitude alone is simple but misses two waves that needed alerts, one of them dangerous, and cries wolf three times; adding DART readings fixes most of that. The local source shows that some tsunamis outrun any message, so the plan must rely on people recognizing the shaking. Crescent City's history, where earlier small surges and false alarms taught people to go back too soon, makes the cost of false alarms concrete.

Standards connections

MS-ESS3-2 (assesses, analyzing and interpreting tsunami data (source location, magnitude, depth, sensor readings and travel times) to forecast arrival and size, and using the forecast to design a warning procedure): Students analyze magnitudes, depths, fault motion and DART readings from past events, calculate arrival times from depth and distance, and use the results to set thresholds in a warning procedure, a mitigation technology. The local-source calculation shows the clarification statement's point that some hazards cannot be forecast with enough notice. The task produces direct evidence toward the PE.

MS-ETS1-2 (practice, evaluating competing procedures systematically against criteria): Each procedure is scored against the same twelve events for misses, false alarms and late warnings, and compared with another group's procedure and with a magnitude-only rule. The criteria and record are supplied, so this practices the PE.

MS-ETS1-3 (practice, combining the best steps of two tested procedures): Two groups compare their scores event by event, identify which steps of each prevented misses or false alarms, and write a combined procedure, as the DART engineers combined three fixes. The cycle is short, so the role is practice.

Roles (rotate each session)

- **Chief forecaster:** Leads the decision steps, makes sure each decision uses only data available at that time, and has the final word on the procedure's wording.
- **Travel-time analyst:** Organizes the arrival-time calculations, splitting the segments among the group, and checks every division with a calculator.
- **Records analyst:** Leads the analysis of the twelve past events and derives the rule that turns a DART reading into a forecast height.
- **Tester and recorder:** Applies the written procedure to each past event exactly as written, fills the test table and totals misses, false alarms and late warnings.

Materials

Item	Quantity	Per	Note
Printed data packet: speed table, path table, DART station locations, record of past events, alert definitions and timing rules	1	student	
Calculator	1	student	Phone calculators are fine.
Colored pencils (green, yellow, red) for marking alert levels	1 set	group	
Class chart for each group's score (misses, false alarms, late)	1	class	

Estimated cost: 1 to 3 per class (estimate) (an estimate; About four printed pages per student at roughly 2 cents a page; calculators and pencils are classroom stock.)

Safety

- No physical hazards beyond ordinary classroom work.
- This lab discusses real tsunamis that took lives. Preview it, do not require personal stories, and allow a student who is upset to work on the calculation section alone or step out.
- Make clear that Port Alder and its record are invented; for real local guidance, students and families should use their county's tsunami information and official alerts.

Teacher preparation and setup

1. Print the packet single-sided so students can lay the record and the test table side by side.
2. Review the alert definitions, which are simplified from the U.S. Tsunami Warning Centers: a warning when waves of 1 m or more are expected (evacuate the harbor district); an advisory for 0.3 m up to 1 m (clear beaches, docks and the harbor); a watch while the threat is being checked; an information statement when no threat is expected.

3. Decide whether to run the lab in one period (analysis questions for homework) or two (the second for testing, combining and q4-q10).
4. Pair groups in advance for the combining step so each pair has procedures likely to differ.
5. Know your school counselor's referral process; some students may have experienced a tsunami alert, an evacuation or a disaster.

Investigation design

Independent variable	The procedure: which data each step uses (magnitude, depth, fault motion, location, DART reading) and the thresholds that set each alert level.
Dependent variable	The number of misses, false alarms and late warnings across the twelve past events.
Controlled	Same record of twelve events for every group; Same times at which data become available; Same 5-minute message time and 30-minute evacuation time; Same alert definitions and the same rule for 'needed' alert levels
Trials	Twelve past events per procedure; each group tests its own procedure, the combined procedure and, in q6, a magnitude-only rule.
Comparison	Scores of the group's procedure, the partner group's procedure, the combined procedure and a magnitude-only rule (warning if magnitude is 8.0 or more).

Student procedure

1. Read the scenario and the timing rules aloud as a group. Underline the three numbers that limit every decision: quake data arrive 5 minutes after the quake, a message takes 5 minutes to reach the public, and the harbor district needs 30 minutes to evacuate.
2. Arrival times: split the eleven path segments among the group. For each segment, look up the speed for its depth in the speed table and calculate time = distance / speed. Add the segments for each source and convert the totals to hours and minutes.
3. DART times: calculate when a tsunami from the North zone passes station D-North and when one from the West zone passes D-West (q1). No station lies between the Local zone and the coast.
4. Analyze the record of twelve past events (q2): look for how wave height at Port Alder relates to magnitude, find the events that break the pattern and what they share, and divide each event's wave height by its DART reading for the North and West zones to find a rule for forecasting height.
5. Write your procedure in the procedure table: no more than six steps, each with when it happens, which data it uses and an if-then rule that ends in an alert level. Every decision may use only data available at that time.
6. Test the procedure: for each of the twelve events, apply your steps exactly as written, without looking at the actual wave until your alert is recorded. Then compare with the alert the actual wave needed, and mark the result correct, miss (alert lower than needed) or false alarm (alert higher than needed). Mark whether each needed advisory or warning reached the public at least 35 minutes before the first surge.
7. Total your misses, false alarms and late warnings, post them on the class chart, and answer q3.

8. Meet your partner group. Compare your procedures event by event, find the step in each that prevented a miss or a false alarm, and write a combined procedure. Test the combined procedure on the events where the two disagreed.
9. Answer q4 through q10 individually, in class or for homework.

Expected observations

- Arrival times at Port Alder: North about 4 h 25 min, West about 9 h 55 min, Local about 20 minutes. D-North is passed about 1 h 24 min after a North-zone quake and D-West about 3 h 46 min after a West-zone quake.
- Wave height rises with magnitude, except E9 (sideways fault) and E12 (300 km deep), which made small waves despite magnitudes of 8.4 and 8.0.
- Wave height divided by DART reading is 0.1 m per cm for every North event and 0.06 m per cm for every West event.
- Procedures that use DART readings to set the alert for distant sources usually reach zero misses and one false alarm (E10, a Local event); magnitude-only procedures score far worse. No procedure gets a Local-zone warning out in time.

Likely difficulties

- Converting decimal hours to minutes (0.419 h is 25 minutes, not 41). Model one conversion: multiply the decimal part by 60.
- Using the actual wave height while 'testing' the procedure, which makes every procedure look perfect. Have the tester cover the last column of the record with a strip of paper until the alert is written.
- Treating a watch as a false alarm. Remind groups that only advisories and warnings move people; a watch that is cancelled is the system working.
- Writing steps that are too vague to apply ('warn if it looks big'). The chief forecaster should insist on numbers in every rule.
- Running out of time. If the period is short, assign half the events to each pair within a group, or move the combining step and q4-q10 to a second period.

Structured debrief

1. Put every group's score on the board. Ask the groups with zero misses and the fewest false alarms to read their DART step aloud. In most classes the best procedures use quake data only to start a watch for distant sources, then let the DART reading set the alert level, which is close to how real warning centers work.
2. Run the magnitude-only rule together (q6): two misses (E2 and E11) and three false alarms (E7, E9, E12). Ask why E9 and E12 were harmless despite their size: a sideways fault barely lifts the seafloor, and a quake 300 km down does not move the seafloor much at all. Tell students real warning centers face exactly this problem in the first minutes, which is why their first message is cautious and later messages are refined with sea-level data.
3. Spend time on the Local zone. The arithmetic shows the wave arrives about 20 minutes after the quake, but data plus a message take 10 minutes and evacuation takes 30. No procedure can close that gap, so

the mitigation must happen before the quake: hazard maps, marked evacuation routes, drills, possibly tall evacuation structures, and teaching that strong or long shaking at the coast is the warning. This is the clarification statement of the standard in action: some hazards allow reliable forecasts and some do not.

4. Close with real numbers. In 1964 the first surge reached Crescent City about four hours after the Alaska quake, and the fourth surge did the most damage after people had gone back. In 2011 the forecast arrival at Crescent City was 7:23 a.m. and the observed arrival 7:34 a.m., about ten hours after the Japan quake. Ask what their Port Alder procedure would have done in each case.

Recording sheet: what students fill in

Lab 3 recording sheet: the Port Alder warning office

Port Alder is an imagined harbor town on a Pacific coast. Its harbor district is low and flat, and its seafloor and harbor shape focus tsunami energy, much like Crescent City's. Three zones can send it tsunamis: the **North** subduction zone (far), the **West** trench (very far) and the **Local** fault zone just offshore. **Timing rules:** earthquake location, depth and magnitude reach the office 5 minutes after a quake; any message takes 5 minutes to reach the public; the harbor district needs 30 minutes to evacuate. **Alert needed:** warning if the wave is 1 m or more; advisory if 0.3 m up to 1 m; none if under 0.3 m. A watch means 'prepare while we check' and does not evacuate anyone.

Tsunami speed at each depth (calculated from speed = square root of 9.8 x depth; not simulated)

Water depth (m)	Speed (km/h)
10	36
50	80
100	113
200	159
500	252
1000	356
2000	504
3000	617
4000	713
5000	797
6000	873

Paths from each source zone to Port Alder, and DART station locations

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Segment	Distance (km)	Typical depth (m)
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Segment	Distance (km)	Typical depth (m)
North 1: deep ocean	2500	4000
North 2: continental slope	150	1000
North 3: continental shelf	40	100
North 4: harbor approach	5	10
West 1: deep ocean	7200	5000
West 2: continental slope	200	2000
West 3: continental shelf	40	100
West 4: harbor approach	5	10
Local 1: slope above the fault	40	2000
Local 2: continental shelf	20	100
Local 3: harbor approach	3	10
DART station D-North: on the North path, 1,000 km from the source	1000	4000
DART station D-West: on the West path, 3,000 km from the source	3000	5000

Teaching dataset for an imagined coast; distances and depths are invented but realistic.

Arrival-time calculations (time = distance / speed)

Segment	Distance (km)	Depth (m)	Speed from table (km/h)	Time (h, to 3 decimals)
North 1	2500	4000		
North 2	150	1000		
North 3	40	100		
North 4	5	10		
North total				___ h = ___ h ___ min
West 1	7200	5000		
West 2	200	2000		
West 3	40	100		
West 4	5	10		
West total				___ h = ___ h ___ min
Local 1	40	2000		
Local 2	20	100		
Local 3	3	10		

Segment	Distance (km)	Depth (m)	Speed from table (km/h)	Time (h, to 3 decimals)
Local total				___ h = ___ min

1. How long after a North-zone earthquake does the tsunami pass D-North? How long after a West-zone earthquake does it pass D-West? Show the calculations and give each answer in hours and minutes.

Answer: D-North: $1,000 \text{ km} / 713 \text{ km/h} = 1.403 \text{ h} = 1 \text{ h } 24 \text{ min}$. D-West: $3,000 \text{ km} / 797 \text{ km/h} = 3.764 \text{ h} = 3 \text{ h } 46 \text{ min}$.

Why: Same method as the path segments: time = distance / speed for the station's depth; $0.403 \times 60 = 24 \text{ min}$ and $0.764 \times 60 = 46 \text{ min}$.

Port Alder record: twelve past earthquakes

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Event	Zone	Magnitude	Depth (km)	Fault motion	Largest DART reading (cm)	Largest wave at Port Alder (m)
E1	North	7.2	25	up-down	0.5	0.05
E2	North	7.9	30	up-down	3	0.3
E3	North	8.3	20	up-down	12	1.2
E4	North	8.8	25	up-down	35	3.5
E5	North	9.1	25	up-down	60	6.0
E6	West	7.6	30	up-down	1	0.06
E7	West	8.2	20	up-down	6	0.36
E8	West	9.0	25	up-down	40	2.4
E9	West	8.4	15	sideways	2	0.12
E10	Local	7.0	20	up-down	no station in time	0.2
E11	Local	7.8	15	up-down	no station in time	1.5
E12	North	8.0	300	deep, inside the sinking plate	1	0.1

Teaching dataset invented for this lab. 'Up-down' faults lift or drop the seafloor; a 'sideways' fault slides the plates past each other.

2. (a) How does the wave at Port Alder generally change as magnitude increases? (b) Which two large earthquakes broke the pattern, and what is unusual about each? (c) Divide each North event's wave height by its DART reading, then do the same for the West events. What rule could the office use to forecast the wave from a DART reading?

Answer: (a) Larger magnitudes generally produce larger waves at Port Alder: from 0.05 m at M7.2 to 6.0 m at M9.1 for the North zone. (b) E9 (M8.4) made only 0.12 m because its fault moved sideways, barely lifting the seafloor; E12 (M8.0) made only 0.1 m because it was 300 km deep inside the sinking plate, so the seafloor hardly moved. (c) North: $0.05/0.5$, $0.3/3$, $1.2/12$, $3.5/35$, $6.0/60$ and $0.1/1$ all equal 0.1 m per cm. West: $0.06/1$, $0.36/6$, $2.4/40$ and $0.12/2$ all equal 0.06 m per cm. Rule: forecast wave (m) = DART reading (cm) x 0.1 for the North zone, x 0.06 for the West zone.

Why: The record was built so the DART-to-coast ratio is constant for each path; students should discover it by division and note it differs by path.

- States the general magnitude pattern
- Identifies E9 and E12 with correct reasons
- Computes both ratios and states a forecasting rule

Our warning procedure (no more than six steps)

Step	When (time after the quake)	Data used	Rule: if ... then ... (alert level)
1			
2			
3			
4			
5			
6			

Testing our procedure against the record

Event	Alert at 5 minutes	Alert after DART (if any)	Final alert	Alert needed (from actual wave)	Correct, miss or false alarm?	Needed alert out at least 35 min before arrival? (Y/N, or none needed)
E1						
E2						
E3						
E4						
E5						
E6						
E7						
E8						

Event	Alert at 5 minutes	Alert after DART (if any)	Final alert	Alert needed (from actual wave)	Correct, miss or false alarm?	Needed alert out at least 35 min before arrival? (Y/N, or none needed)
E9						
E10						
E11						
E12						

Scores

Procedure	Misses	False alarms	Late warnings
Ours			
Partner group's			
Combined			

3. Summarize how your procedure scored. Which event gave it the most trouble, and why?

Answer: Group-specific. A strong procedure scores 0 misses, 1 false alarm (E10) and 1 late warning (E11). The Local events usually give the most trouble, because there is no DART reading and no time to wait for one.

Why: Students should name a specific event and the data that was missing or misleading.

- Reports the three counts
- Names the hardest event and explains why

Analysis questions: answer key

4. Give the arrival time at Port Alder for a tsunami from each zone in hours and minutes. For a North-zone tsunami, if the office waits for the D-North reading and then takes 5 minutes to send the message, how much time is left before the first surge, and is that enough for the 30-minute evacuation?

Answer: North: $3.506 + 0.421 + 0.354 + 0.139 = 4.420$ h = 4 h 25 min. West: $9.034 + 0.397 + 0.354 + 0.139 = 9.924$ h = 9 h 55 min. Local: $0.079 + 0.177 + 0.083 = 0.340$ h = about 20 min. North timing: D-North reading at 1 h 24 min + 5 min message = 1 h 29 min; 4 h 25 min - 1 h 29 min = 2 h 56 min left before the first surge, far more than the 30 minutes needed.

Why: Segment times are distance divided by the table speed for the segment's depth; decimals of an hour are multiplied by 60.

Also acceptable: Accept answers within a minute or two from rounding, such as 4 h 26 min or 2 h 55 min.

5. On the North path, the last 45 km (segments North 3 and North 4) take about as long as the first 350 km of deep ocean would. Use the speed table to explain why, and explain why the wave also grows taller over those last 45 km.

Answer: North 3 and North 4 take $0.354 + 0.139 = 0.493$ h, about 30 minutes, for 45 km, because the water there is only 100 m and 10 m deep and the speed falls to 113 and 36 km/h. In the 4,000 m deep ocean the wave moves at 713 km/h, so 30 minutes covers about 350 km. As the front slows in shallow water, the water behind catches up and the same energy is squeezed into a shorter, shallower wave, so its height grows.

Why: Students should use the depth-speed table for the timing and the slowing-and-bunching idea for the growth.

- Uses the speeds for shallow and deep water from the table
- Explains that the wave slows in shallow water
- Explains growth by the wave bunching up with its energy squeezed into less length and depth

6. Test a magnitude-only rule on the record: 'warning if magnitude is 8.0 or more; otherwise no alert.' Count its misses and false alarms. Use events E9, E11 and E12 to explain why a good procedure needs more than magnitude.

Answer: Magnitude-only results: E1 none (correct), E2 none but advisory needed (miss), E3 warning (correct), E4 warning (correct), E5 warning (correct), E6 none (correct), E7 warning but only advisory needed (false alarm), E8 warning (correct), E9 warning but none needed (false alarm), E10 none (correct), E11 none but warning needed (miss), E12 warning but none needed (false alarm). Total: 2 misses, 3 false alarms. E9 shows that a sideways fault barely moves the water, and E12 that a very deep quake barely moves the seafloor, so magnitude alone overwarns; E11 shows that a moderate local quake can still be dangerous because the town is so close. A good procedure also uses location, depth, fault type and DART readings.

Why: Students apply a fixed rule to every row and compare with the needed alert; the exceptions show why warning centers refine their first message with sea-level data.

- Correct counts: 2 misses and 3 false alarms
- Explains E9 and E12 by fault motion and depth
- Explains E11 by distance from the town
- Concludes that more than magnitude is needed

7. For a Local-zone earthquake, show with numbers that no procedure can give the harbor district 30 minutes to evacuate. What should Port Alder do instead? Name at least two actions taken before any earthquake happens.

Answer: Arrival about 20 minutes after the quake. The earliest message reaches the public at $5 + 5 = 10$ minutes, leaving about 10 minutes, but evacuation takes 30, so the town is about 20 minutes short; even an instant message (5 minutes) would leave only 15. Port Alder should prepare beforehand: teach residents that strong or long shaking at the coast means go to high ground or inland at once without waiting for an alert; mark evacuation routes and post tsunami hazard maps; hold drills; build or designate tall, strong evacuation structures in the low harbor district; and keep new homes and schools out of the hazard zone.

Why: This is the clarification statement's contrast: some hazards do not allow a forecast with useful notice, so mitigation must be done in advance.

- Shows the timing arithmetic
- Concludes no procedure can provide 30 minutes
- Names at least two preparation measures, including shaking as the warning

8. Describe the combined procedure you and your partner group wrote. Which step came from each group, what problem did each step solve, and how did the combined procedure score compared with both originals?

Answer: Group-specific. Example: 'Our procedure used DART readings with the 0.1 and 0.06 rules but issued no alert for Local quakes under M7.5, so it missed E11. Their procedure warned for every Local quake of M7.0 or more but used a 1.5 m DART threshold, so it under-warned E3. The combined procedure kept their Local rule and our DART rule: 0 misses, 1 false alarm (E10), and E11 still late because no warning can be in time.'

Why: The point is identifying which step of each procedure solved which problem and testing the combination.

- Names the step taken from each group
- Links each step to the event it fixed
- Reports the combined score against both originals

9. Write a rule for when your office should end a warning, and explain it using what happened at Crescent City in 1964.

Answer: Example rule: keep the warning or advisory until at least 3 hours after the first surge and until the harbor gauge has shown waves under 0.3 m for at least an hour; the end must be announced by officials. Reason: a tsunami arrives as several surges, and at Crescent City in 1964 the first surge was small, some people went back downtown, and the fourth surge, about 6 m, was the most destructive.

Why: Any rule that keeps the alert well beyond the first surge and ties ending it to measured conditions earns credit.

- A specific rule with a time or measurement
- Uses the 1964 sequence as evidence

10. Lowering your thresholds would catch every dangerous wave but cause more false alarms. Why is a false alarm a real cost and not just an inconvenience? Use the Crescent City story to support your answer.

Answer: Each false alarm costs money and lost work, and moving people has its own risks, but the biggest cost is trust: people who have evacuated for nothing are slower to leave next time. Before 1964, Crescent City residents had seen tsunami alerts that brought only small surges, and during a lull after the first small surges some went back to the waterfront; several of them died in a later, larger surge. A procedure has to balance missing a dangerous wave against warning so often that people stop listening.

Why: Students should name trust or complacency as the hidden cost and tie it to the historical case.

- Names a concrete cost of false alarms, especially lost trust
- Uses the Crescent City history as evidence
- Recognizes the trade-off with misses

Individual evidence of learning

Each student submits the recording sheet (arrival-time table, q1, q2, the procedure, the test table, the scores and q3) and answers to q4 through q10. The arrival-time table with q1, q4 and q5 is the evidence for forecasting arrival from depth and distance; q2, q6 and the procedure test are the evidence for analyzing hazard data to inform a mitigation; q7 and q10 show judgment about the limits of forecasting.

Assessment criteria

Criterion	Proficient looks like
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Travel-time forecasting	Correct speeds and segment times, totals of about 4 h 25 min, 9 h 55 min and 20 min, and correct DART pass times, with decimal hours converted correctly (table, q1, q4).
Analyzing the record	States the magnitude pattern, identifies E9 and E12 as exceptions with reasons, and derives the 0.1 and 0.06 rules from the data (q2, q6).
Procedure design and testing	A procedure of six steps or fewer with numerical thresholds that uses only available data, tested honestly on all twelve events with correct counts.
Evaluating and combining	Compares two procedures event by event, combines the steps that solved specific problems, and reports the combined score (q8).
Limits of forecasting	Shows numerically that the Local zone cannot be warned in time and proposes preparation measures; explains the cost of false alarms with the Crescent City history (q7, q9, q10).

Accessibility adaptations

- Provide a speed-lookup strip with only the depths used in the paths, and a worked first row of the arrival-time table.
- Offer a procedure template with blanks ('At ___ minutes, if ___ is at least ___, then issue a ___') for students who need structure.
- Students who find long tables hard to track can use a ruler or card to follow one row at a time; enlarge the record to 14-point type for low vision.
- Allow the procedure to be presented as a flowchart drawing instead of a table, and accept spoken answers to q7 and q10.

Low-cost alternative

The lab is already paper only. Without a printer, project the data tables and have groups copy only the rows they need; the arrival-time table can be split so each student computes one source and the group shares results.

Model limitations

This activity has not been tested with students by the authors. Port Alder, its paths and its record are invented, though the speeds follow the real long-wave rule and the alert levels are simplified from the U.S. Tsunami Warning Centers. Real tsunamis bend around seafloor features and do not follow straight segments of one depth; real arrival-time forecasts use detailed seafloor maps and computer models. Real coastal heights depend on the shape of each beach and harbor and are not a fixed multiple of a DART reading. Real warning decisions also use many DART stations, coastal tide gauges and updated earthquake information over time.

Teacher notes

Check the arrival-time table first; most later errors come from decimal-hour conversions. In the test table, insist that the alert is written before the actual wave is uncovered. The record is built so that the DART ratios are exact (0.1 and 0.06); real coastal amplification varies by place and event. A model procedure that scores 0 misses and 1 false alarm: (1) at 5 minutes, for a shallow Local quake of M7.0 or more, issue a warning at

once; (2) for a shallow North or West quake of M7.5 or more, issue a watch, otherwise an information statement; (3) when the DART reading arrives, forecast the wave (x 0.1 North, x 0.06 West) and issue a warning for 1 m or more, an advisory for 0.3 m to under 1 m, or cancel; (4) send every message within 5 minutes; (5) end alerts only after 3 hours and calm gauge readings. Applied to the record it gets E1-E9 and E12 right, false-alarms on E10 and is late on E11.