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Summary of Section 10, Responding to Levee Breaches

Purpose:

When levee failure events occur, repair activities are typically initiated to close the breaches and recover the islands. Section 10 presents an emergency response and repair (ER&R) model to estimate the time, material, and associated costs to repair damaged and breached levees and dewater flooded islands.

Methods of Analysis:

No emergency response plan was available to define a business-as-usual (BAU) approach to levee repair for the Delta, so the consulting team developed an ER&R model to use as a BAU approach. The consulting team developed the model based on interviews with contractors and quarry officials to estimate the resources (e.g., quarry production and barges) that could be used in the ER&R analysis for various events and conditions.

Main Findings:

The ER&R model develops a priority list for repair of flooded and threatened islands. Table 10-6 shows the results for these two categories of islands: Category A (threatened but not flooded) and Category B (islands already flooded). Actual results for repair times and repair costs are presented in Section 13, which addresses the specific cases that are used to develop risk results from several different levee breach events.

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When a levee failure event occurs, including those that involve multiple breaches on a number of islands, repair activities will be initiated to close the breach(es) and recover the island(s). The objective of the emergency response and repair (ER&R) part of the risk analysis is to estimate the time and material required, and the associated costs, to repair damaged and breached levees and dewater flooded islands.

The Emergency Response and Repair Technical Memorandum (TM) (URS/JBA 2008d) presents a detailed description of the ER&R analysis. The ER&R model has been developed using past Sacramento–San Joaquin River Delta (Delta) levee repair experience of the California Department of Water Resources, contractors, and local quarries.

Because an emergency response plan was not available to define a business-as-usual (BAU) approach to levee repair for the events that are modeled in the risk analysis, the development of the ER&R model required that a BAU approach be defined. Also, the Delta Risk Management Strategy (DRMS) consulting team conducted assessments based on interviews with contractors and quarry officials to estimate the resources (e.g., quarry production) that could be used in the ER&R analysis to analyze the response to levee failures in the Delta.

10.1 LEVEE FAILURE SEQUENCES

Levee failures and/or non-breach damage to levees in the Delta could result from earthquakes, floods, and normal (sunny-day) events. Hydrologic events and earthquakes can result in multiple levee failures on multiple islands as a result of a single event (e.g., single earthquake). In the case of an earthquake, there will also be non-breach levee damage (see Section 6 and the Levee Vulnerability TM [URS/JBA 2008c]) that must be repaired as part of the effort to recover an island.

As described in Section 4, a levee failure event may involve (depending on the initiating event and details of the sequence) the following:

- One or more levees may fail on one or possibly multiple islands.
- In the case of a seismic event, possible non-breach damage (with no levee failures and therefore no island flooding) may occur on some islands. These islands will require levee repair, but not dewatering.
- The repair of an island that is flooded will involve the following:
  - Closure of the levee breach
  - Placement of rock on levee interior slopes and possible repair of levee interiors as a result of erosion due to wind waves
  - Repair of non-breach damage (in the case of a seismic event)
  - Dewatering of the island
- Once a flooded island is closed and non-breach seismic damage is repaired, the island is dewatered.

The repair of failed and damaged levees and the dewatering of flooded islands are the first steps in the process of recovering from a levee failure event. At the same time, the timing of levee breach closures and the dewatering of islands is a continuation of the levee failure sequence because of the effect that open islands have on the hydrodynamic response of the Delta after the initiating event (e.g., the earthquake that caused the levee failures).

10.2 EMERGENCY LEVEE REPAIR ANALYSIS

When levee failures occur, the method of repair involves the placement of rock to stabilize the damaged levees and to close breaches. This approach, based on past experience (BAU) includes capping of breach ends to stabilize the breach before attempts are made to close it. Once the breach ends are capped, the breach and scour hole are filled with rock until closure is achieved. In addition, capping of the waterside slope is often required to limit seepage through the repaired sections. Due to wind waves that are generated on the flooded island, placement of erosion protection on the interior levee slopes is required.

10.2.1 Levee Emergency Response and Repair Model

When a levee failure event occurs in the Delta, one or multiple islands may be flooded, and in the case of a seismic event there may be a number of islands whose levees have experienced damage, but have not failed. The ER&R model is a time simulation model that tracks the repair activities (described later) on each island, until all of the repairs have been completed and the islands dewatered. Repair activities that are tracked in time in the analysis include:

- Levee breach growth before capping
- Cumulative levee interior erosion on flooded islands
- Quarry rock production rates which increase during the period of repair
- Rock and soil placement rates for breach capping, breach closure, interior erosion protection and repair, and non-breach damage repair
- Repairs and dewatering costs

Figure 10-1 shows a schematic of the elements of the DRMS levee emergency response and repair approach. Elements of the analysis are summarized in the following paragraphs.

Figure 10-2 shows a schematic of the timeline of repairs for a levee failure sequence. The timeline illustrates the progression of levee repairs, ongoing damage, and quarry production.

Levee Failure Sequence. A levee failure event (sequence) is defined in terms of:

- Islands that are flooded as a result of a levee failure
- Number and location of the breaches on each island
- Location (identified by levee reach/sector) and length of non-breach damage in the case of an earthquake on each flooded island
- Damaged, but non-flooded islands
- Location (identified by levee reach/sector) and length of non-breach damage in the case of an earthquake on each non-flooded island
- Time of year the event occurs (month)

A sequence is also defined by the type of water year, which is important for the hydrodynamic and water analysis part of the risk analysis (see Sections 4 and 11).

Repair Types and Business as Usual. In the ER&R analysis, the response to levee damage and breaching is divided into a series of repair types:

- RT1 – repair non-breach damage on non-flooded islands
- RT2 – protect the levee interior slopes on a flooded island against wind-wave damage, or repair damage if it has already occurred
- RT3 – repair non-breach damage on a flooded island
- RT4 – stabilize breached levees by capping the levee ends at the breach
- RT5 – breach closure
- RT6 – island dewatering

These repairs are carried out for all islands that are defined in a sequence. As part of the ER&R analysis, repair types can be prioritized or eliminated (not performed) from one island to the next.

In the DRMS Phase 1 analysis all six repair types could be carried out for all islands, and would be selected as dictated by the damage on the island. This is the BAU approach to responding to levee failures in the Delta. It should be recognized that other sequences of repair or extent of repair, after a major event in the Delta, could be different from the proposed sequence of emergency repair proposed here.

Island Priority and Work Order Priorities for Levee Repair. For a given levee failure sequence, islands are assigned a priority. The island priority system used in the DRMS Phase 1 analysis is described in Section 10.4. As resources become available for a particular repair type, repairs begin on the island next on the priority list.

The repairs that are required on an island are prioritized in a work order that is generated for each island. The work order repair priorities for flooded islands are (1) RT4, (2) RT5, (3) RT3, (4) RT2, and (5) RT6. Note, due to the varying availability of equipment resources and the completion of different repair types on islands that have higher priority, repairs of a given type may not be carried out in the priority listed above. For instance, if equipment becomes available to initiate interior levee slope protection and repair (RT2) because the work on other islands has been completed, these repairs are initiated on the island next in line for repairs.

For islands that are not flooded but have non-breach damage, RT1 repairs are carried out.

Quarry Production. The San Rafael Rock Quarry (SRRQ), the major source for rock and marine delivery, has a certain production capability. Based on discussions with the Dutra Group (owners of the SRRQ), an assessment was made to determine, in the case of a major event in the Delta, what production levels could be achieved to meet the repair demands in the Delta. As described in the Emergency Response and Repair TM (URS/JBA 2008d), the Dutra Group provides estimates of the quarry production and delivery capacities that can be achieved. The increased capacities depend on the level of demand and include construction of a docking facility in San Rafael to increase loading and delivery capacity.

ER&R Analysis Results. There are two primary outputs that are generated by the ER&R analysis. The first is the estimated cost of the levee repair and island dewatering. This result is an input to the economic consequence analysis (see Fig. 10-1). The second result is the location of island breaches and the timing of their closure. This information serves as input to the Water Analysis Module (URS/JBA 2007e), which estimates the hydrodynamic response of the Delta to the levee failure event (see Figure 10-1).

10.2.2 Analysis Conditions and Business as Usual

Following the BAU approach to the Phase 1 analysis, the SRRQ is the source of rock required for breach repairs and the only source of material for marine-based activities. The SRRQ, located in San Rafael, California, and owned by The Dutra Group, is the primary supplier of quarry products for the Delta. Consequently, the SRRQ has the ability to respond in a timely manner in an emergency to directly load barges with product for delivery to the Delta.

Placement of erosion protection and repair of erosion damage can be carried out from land, if access permits. In this case, material is sourced from local quarries. Although BAU practices are summarized above, it is recognized that no failure of many islands (20 or more) at the same time has yet occurred to provide an experience base to define a usual or typical approach to emergencies involving tens of flooded islands in the Delta[1].

In the analysis, it is assumed an emergency response plan is in place including necessary pre-event preparedness[2]. As the magnitude of a levee failure event increases, the effect of a lack of emergency preparedness (in the context of the Phase 1 analysis and BAU) on the overall repair durations diminishes. Therefore, the model does not quantitatively account for such emergency preparedness preparations beyond the assumption that such preparations enable the model to meet the SRRQ production rates.

When a major event in the Delta occurs in which there are multiple levee failures and islands flooding, a number of factors will come into play that will determine how the emergency is managed and as a result what the eventual impact will be. These factors include the decisions that will be made by the governor and others in the chain command with respect to priorities that will be set, the range of emergency powers that will be exercised, the allocation of resources, the potential suspension of regulations (e.g., environmental regulations or local noise restrictions near the SRRQ), and repair priorities. The DRMS consulting team established the following conditions based on BAU for the ER&R analysis:

- It is assumed all flooded or damaged islands will be repaired after an event.
- Within days of a sequence of failures, local regulations will be eased or set aside to allow the SRRQ to operate on a 24-hour basis.

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[1] Alternative rock sources will be considered in Phase 2 as a potential approach for enhanced emergency response.

[2] In fact this is not the case. However, for purposes of conducting the analysis, it is the basis from which the analysis is carried out. Delays and uncertainties associated with decision-making during an emergency in the Delta (the need to establish repair priorities; the political influences that may factor into the decision-making process; difficulties in establishing contracts with suppliers, etc.) are not modeled.

- Sufficient transportation equipment (i.e., deck barges, scows, and tugs) will be made available immediately to support initial material production rates, so that material supply capacity remains the constraint.[3]
- Resources (i.e., materials, equipment, and trained labor) are assumed to be available and will not be compromised by demands outside the Delta that occur as a result of the same seismic or flood event. Damage that occurs to assets other than levees will not put a demand on resources required to support levee breach repairs. This may be unconservative in the case of a major seismic event in the Bay Area (e.g., an earthquake on the San Andreas Fault) that causes significant damage to infrastructure systems (e.g., port facilities or bridges,) that require marine equipment. Even for these events, the governor may give priority to levee repair and restoring the Delta, such as in the case of a drought. For events that are more local to the Delta (e.g., an earthquake on the Southern Midland Fault), this assumption is reasonable.
- The effect of earthquake aftershocks which could potentially damage levees or compromise repair operations is not considered in the risk analysis (see Section 4).
- No constraints exist for dewatering resources. The need for pumps and related material (e.g., piping) to dewater an island is not required immediately after a levee failure since dewatering will start after breaches have been closed and damaged levees are stabilized (in the case of a seismic event), which will take a minimum of 3 to 4 weeks typically. As a result, time is available to procure pumps and other needed equipment. With highway and rail transportation available in the region and the country, the geographic accessibility for dewatering resources is at least continent wide. Further, experience from the response to Hurricane Katrina indicates pumping resources world-wide can be made available (Times-Picayune 2005) in a timely manner.

These conditions, which are based on BAU, are a reasonable basis on which to define the bounds of the analysis and to establish a baseline measure of risk.

10.3 ONGOING DAMAGE

In the period following a levee failure event, damage will continue to accumulate until repairs have been made. This damage includes erosion of exterior levee slopes, potential levee overtopping due to flooding, interior levee erosion on flooded islands as a result of wind waves, and erosion of breach ends as a result of flows into and from islands during tidal exchanges. Prevention of ongoing damage (such as remediation of damaged sections of levee, capping of breached levee ends, and interior levee protection) is one element of the emergency response to levee failures. Each source of ongoing damage is discussed briefly in the following subsections.

[3] This condition is based on the discussions with Dutra staff, the analyst's familiarity with Dutra's fleet and with other marine equipment generally active in the Bay Area. It also considers equipment available from other West Coast locations, given a mobilization period, to support increased production rates later in the repair period.

10.3.1 Exterior Damage

In the case of slumped levee sections (which may occur as a result of a seismic event) on a flooded island, overtopping from the exterior (from an episodic storm) will not result in further breaches, since equal heights of water occur on both sides of the levee. However, exterior damage could occur as a result of waves breaking on the crest instead of on the riprap, as a result of an exterior episodic event. This type of damage would be eroding (similar to interior slope erosion) over a short period of time, since it is episodic. Thus, it is likely not an important factor (it adds a little more to the material requirement of the already damaged levee section) and is, therefore, not included in the analysis.

10.3.2 Breach Growth

Breached levee sections will grow in length over time. A review of historic breaches in the Delta, and in particular those that have not been closed indicates that breach growth in the short term is not significant and therefore this source of continuing damage was not included in the analysis.

10.3.3 Wind-Wave Erosion

Wind-wave erosion on the levee's interior slopes will act on the intact and damaged levee sections throughout the repair period. This erosion manifests itself as additional (continuing) damage on an island (e.g., the Jones Tract failure in 2004). During a given levee failure event, rock will be required to add rip rap to provide erosion protection on levee interiors and/or to repair erosion damage that occurs.

The wave erosion that could occur following a levee failure event is random, due to the stochastic nature of winds (direction, duration, and velocity). In the DRMS analysis, levee erosion occurs following each levee failure event. The rate of erosion was estimated from a simulation that models the randomness of winds and waves in the Delta. The result is a set of mean erosion curves for each island that accumulates the amount of erosion until levee interior protection/repairs are carried out (see the Emergency Response and Repair TM for a more detailed description of the analysis [URS/JBA 2008d]).

The elements of the levee interior slope erosion model are illustrated in Figure 10-3 and are summarized in the following:

- Sets of mean erosion curves that predict the amount of erosion as a function of time are defined for each island sector (each island is subdivided into eight sectors, each consisting of 45 compass degrees)[4].
- With each day that passes following flooding of an island, erosion damage is accumulated on the intact and damaged levee sections of each island sector, based on wind and wave forces as generated by the wind/wave module (see Section 8).

[4] The levee reaches that are modeled in the analysis are mapped into the eight sectors on each island. The approach of modeling the islands by eight sectors is conservative, since the erosion model is applied to every foot of levee in the sector, which will not be the case since the winds will not directly impact every foot of the levee in the most detrimental direction for every event (i.e., wind waves will not approach every foot of the levee in a sector at 90 degrees, which is what is assumed in the analysis).

- Erosion occurs at the same rate along the entire levee perimeter of each island sector (as noted earlier, this is conservative).
- Erosion continues to act on the levee width (which is different for intact vs. damaged/slumped levee sections) at mean higher high water. When the levee's width has been eroded down to a threshold level of 6 feet, it is assumed that the remaining portion of the levee fails, and the entire levee cross section above mean lower low water collapses and must be replaced for that specific levee segment.
- Accumulation of interior levee erosion damage on an island stops when the levee section fails (as defined above) or when laying of rock for protection of the levee interior is commenced. The amount of rock laid is based on the amount required for the layer of protection plus the amount required to replace the eroded section that has been accumulated to that point.

10.3.4 Secondary Breaches on Non-flooded Islands

When a seismic event occurs, levee reaches on an island may be damaged, but not breached. Due to the damage that has occurred on these non-flooded islands (crest slumping and loss of freeboard, embankment disruption), the damaged levees could fail at a later time, as a result of a storm event that causes overtopping and subsequent breach. Depending on the levee failure sequence (the number of islands involved and the extent of damage that must be repaired), the repair period could extend many months or years. As the exposure of non-flooded islands (that have not been repaired) increases, the probability that an island will experience high water levels due to flooding and/or episodic wave events that could lead to overtopping, levee failure and island flooding increases as well.

Factors that contribute to the potential for subsequent failure of non-flooded islands include:

- Timing of levee repairs and their completion (following the event)
- The extent of the non-breach damage that has occurred on an island (e.g., 500 feet or 5,000 feet of damaged levee)
- Probability of experiencing high-water elevations and/or episodic wave events that erodes damaged levee sections resulting in a breach, overtops the levee, or causes a piping failure through the damaged embankment.
- The potential for local efforts to successfully initiate levee protection actions (e.g., rock placement, visquine placement, or sandbagging) that avoid a possible failure.

Each of these events is random (stochastic) in nature. In the ER&R analysis, a simplified model is used to assess the probability that damaged, non-flooded islands will fail.

10.4 PRIORITIZING REPAIRS

Deciding on the relevant factors and relative priorities for allocating scarce resources to levee repairs in an emergency situation depends on the location and magnitude of the levee failure event (i.e., the number of levee failures that occurred and the number of islands involved). As part of the levee emergency response and repair analysis some structure for making these decisions is required to guide the order of repairs that must be made.

This section discusses the factors considered to establish a BAU approach to levee repair. It is worth noting that actual priorities set in a real emergency will undoubtedly prove to be different considering the situation that must be addressed.

Purpose. The purpose of the prioritization approach is to allocate levee repair resources for a levee failure event. In the analysis, once an island is designated for repair, all repairs that are required are made for that island.

Objective. The objective that has been established for this priority system is very broad. The system is to allocate resources to island repairs in a way that best responds to the interests of the state (given BAU). The system developed attempts to be clear, unambiguous, and workable.

Factors, The factors considered in the priority system include the following:

- Flooded state – Is an island or tract already flooded or is it in danger of flooding?
- Population – What is the population of the island or tract?
- Infrastructure – What infrastructure is flooded (or threatened) and what are the impacts?
- Export Salinity Impact – What is the relative impact of this island or tract (or group of areas) on salinity at the export pumps and on the ability to export?

For each of these factors, the islands (analysis zones) are ordered going from most important to least important. The order for a factor is fixed; it does not vary from levee failure sequence to sequence.

Repairs for Flooded Islands. The sequence of repairs for flooded islands is presented below:

- Cap all breach ends
- Control ongoing interior damage
- Close the breach
- Repair non-breach damage
- Pump out the island

The proposed repair sequence is based on experience with emergency response in the Delta. The highest priority is to control ongoing damage. Thus, marine repair resources are allocated to capping and interior protection first on all islands (as long as they can be used effectively). Then they move on to breach closure and island pump out on an island priority basis.

Repairs for Non-flooded Islands. Repairs are made on damaged non-flooded islands as the top priority. Thus, RT1 is the top priority for all "significant" islands.

Significant Islands. In this analysis, "Significant" islands are defined on the basis of population, infrastructure, and flooding volumes/locations that impact salinity relative to water export. The list of "significant" islands (or analysis areas) is provided in Table 10-1. All "significant" islands are addressed by this priority system in Categories A and B, as explained below.

Prioritization of Levee Repairs. Three priority categories are established as follows:

- A – Islands/areas threatened but not yet flooded
- B – Islands/areas already flooded

- C – All islands/areas not addressed by Categories A or B (Delta and Suisun Marsh islands not listed in Table 10-1)

For a given levee failure sequence involving a series of flooded and/or damaged islands, each island is placed in one of the above categories. The highest priority is given to Category A, then B, then C.

Within a category, islands are ranked based on the factors identified above (e.g., population). This ordering is used to define the island priority and the work order for individual repair types that are input to the analysis. The levee emergency response and repair model uses the island and work order priorities that are set (as defined by A1 through A16; see Table 10-2 for the list of priorities) in the order specified. If no assignment is found in Priority Category A (threatened but not flooded) the search continues in Priority Category B (islands already flooded). Finally, model considers Priority Category C (islands that were not included in A or B).

Population. The population categories were established based on the estimated 2005 population. Where population data were not readily available, estimates were based on the number of households as estimated by the DRMS economic consequence evaluation team. Four population groups were defined: 10,000 or more, 5,000 but less than 10,000, 1,000 but less than 5,000, and 500 but less than 1,000. Areas with less than a population of less than 500 were not considered to have population preference. Island priorities based on population are given in Table 10-3. Within each group, islands are listed in priority order.

Infrastructure. In the case of islands that have flooded, much of the critical infrastructure can be put back into service before an island is repaired and pumped out. This situation is true for interstate highways, electrical transmission lines, the Mokelumne Aqueduct, and the railroad. Thus, the only infrastructure items that enter into a decision on which flooded island should be repaired next are as follows:

- State highways (12, 4, and 16)
- Natural gas storage and retrieval (McDonald Tract)

Since traffic can be rerouted around the impassable area, the state highways generally do not get a high priority (for flooded islands). For non-flooded islands, the presence of a state highway is considered to be associated with a higher priority.

The DRMS economic consequences evaluation team analyzed the effect of infrastructure damage and downtime to business (see the Economic Consequences TM [URS/JBA 2008f]) and found that the loss of gas storage and retrieval on McDonald Tract would not have a major regional impact, so it does not receive a high priority except where flooding might be prevented.

When an island has been damaged, but not flooded, the infrastructure priority is based on preventing damage to:

- Mokelumne Aqueduct
- State highways
- Railroads
- MacDonald Island’s natural gas storage and retrieval facility

Infrastructure priority groups are listed in Table 10-4. Within each group, islands are listed in priority order.

Salinity. The salinity priority categories are based on the DRMS and other hydrodynamic calculations that have been performed using the RMA Bay-Delta model (RMA 2005), After reviewing the available hydrodynamic calculations, the DRMS consulting team set priorities for individual islands that, when flooded with saline waters, would be most disruptive to water exports. Hydrodynamic calculations indicate that salinity intrusion deep into the southern Delta must be avoided if possible by defending threatened south Delta islands (JBA 2005). These calculations found that south Delta islands were the dominant interference for water exports. As a result, if salinity intrusion on these islands occurs, levee repairs to the southern Delta islands is given the top salinity priority.

Based on a review of the available hydrodynamic calculations involving multiple islands flooding and alternative levee repair sequences, a prioritization for levee repairs and salinity importance was set. The south Delta islands are addressed as Old River first, then Middle River, and then San Joaquin River. Next, the islands in the western Delta are important. Lastly, islands in the eastern and northern Delta are considered. Modeling experience suggests the eastern and northern islands that are flooded do freshen while the southern, central, and western Delta islands are repaired. The salinity priority groups are listed in Table 10-5. Within each group, islands are listed in priority order.

Within the three factors considered (population, infrastructure, and salinity), population and infrastructure are given higher priority when an area is unflooded and damage might be prevented than would be the case when the flooding has already occurred.

Within each priority category (A and B) the relative priority given to population versus infrastructure versus salinity is based on a subjective consideration of the categories' overall "interest to the state."[5] When flooding might be prevented on a threatened (damaged island), the highly populated areas are given a high priority. Thus, areas with 5,000 or more residents get highest consideration. At the same time it is important to avoid disrupting the state's water supply and also to prevent damage to other infrastructure. Thus, these factors dominate (and compete for resources) where the goal is to prevent further flooding (flooding on non-flooded islands). A salinity group comes next, then an additional population group, an infrastructure group and so forth.

When flooding has occurred on an island(s), the "state's interest" gives a high priority to repairs that restore the state's water supply. At the same time, there is also a competing interest to restore flooded islands that have large populations. To meet these needs, a portion of the marine-based repair resources is allocated to areas with populations of 5,000 or more. Otherwise, full attention is devoted to the repair of islands important to restoration of water exports in priority order.

Table 10-6 presents the island/area priority order that results for non-flooded (Category A) and flooded (Category B) islands/areas addressed as "significant."

[5] The priority system that is implemented in the levee emergency response and repair analysis is a mechanism for carrying out the analysis. It is based only on general principles discussed with DWR during the course of the project. The priority system that is implemented is a starting point for carrying out the risk analysis (a means of establishing a baseline), given the fact an emergency response plan and a priority system do not exist.

For the islands and tracts not listed above (Category C), priority is assigned on the basis of island acreage.

10.5 IMPLEMENTING LEVEE ER&R IN THE DELTA

The ER&R model is used to estimate the time and material required to recover from levee failure(s). It estimates the time to repair islands and associated costs to stabilize damage levee section, prevent further damage, close breaches, and dewater flooded islands following levee failure(s). Given a sequence that identifies a set of levee breaches and/or damage throughout the Delta, the ER&R model makes an assessment of the ability to respond.

As discussed in Section 10.2, a number of factors will affect the repair of levees after a major event. These factors range from the lack of an emergency response plan that includes a strategy for undertaking the repairs to the response of state leaders to an emergency in the Delta. In this context, the ER&R model provides a starting point for evaluating risks and examining the role of emergency response strategies. Assumptions have been made to carry out the emergency response, because no detailed emergency response plans exists for the Delta and the region as whole that covers the issues listed below:

- After a major seismic event in the Bay Area, barge navigation will be interrupted if bridges have collapsed. In the ER&R analysis no interruption to barge navigation are considered.
- The time required to put contracts into place with companies that will participate in the levee repairs, which could vary from event to event, has not been addressed.
- If the SRRQ is required to obtain permits to increase their production (such as the construction of a second loading facility, it is unknown if this can be done in a timely manner, or if the permitting requirements can be waived. The potential impact of delays due to regulatory or other requirements as they might effect the SRRQ production and delivery have not been considered in the ER&R analysis.
- It may take longer than 180 days (a threshold assumed in the analysis) to bring other sources of material on line. The State of California will have to decide on when to call in help from non-local sources, such as Catalina Island, Canada, or Mexico.
- After a seismic event numerous projects may compete for the same resources. The state will have to prioritize competing projects. We assumed that some of the needed material and equipment will not be readily available.

Actual results for repair times and repair costs are presented in Section 13, which addresses specific cases that are used to develop risk results from several different levee breach events.

Table 10-1 Significant Islands for Repair Prioritization

(Based on Population, Infrastructure, and Volume/Salinity)

Bacon Island	Rough & Ready Island
Bethel Island	Ryer Island
Bishop Tract	Sacramento Pocket Area (196)
Bouldin Island	Sargent-Barnhart Tract 2 (188)
Brack Tract	Sherman Island
Bradford Island	Shima Tract
Brannon-Andrus Island	Shin Kee Tract
Byron Tract 1 (127)	SM-124 (Suisun Marsh, Southwest of Suisun City)
Byron Tract 2 (128)	Staten Island
Canal Ranch	Sutter Island
Coney Island	Terminous Tract 2 (87)
Discovery Bay	Twitchell Island
Empire Tract	Tyler Island 1 (Walnut Grove; 62)
Fabian Tract	Tyler Island 2 (63)
Grand Island	Union Island 1 (117)
Hastings Tract 2	Veale Tract 2 (129)
Holland Tract	Venice Island
Hotchkiss Tract 1 (108)	Victoria Island
Jersey Island	Webb Tract
Jones Tract (Upper and Lower)	West Sacramento North
King Island	West Sacramento South 1
Mandeville Island	Woodward Island
McDonald Tract	Wright Elmwood Tract (190)
Medford Island	Wright-Elmwood/Sargent-Barnhart Tract (191)
Netherlands 3 (142)	Zone 126 (Pico Naglee, north Tracy)
New Hope Tract	Zone 148 (E of Sac River near Hood)
Orwood Tract (20)	Zone 157 (Smith Tract, West Stockton)
Palm Tract (16)	Zone 158 (Weber Tract, West Stockton)
Pierson District 1 (149)	Zone 159 (Boggs Tract, West Stockton)
Quimby Island	Zone 185 (Northwest Stockton)
RD 17 Mossdale (Lathrop Area)	Zone 197 (E of Sac River N of Hood)
Ringe Tract	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Rio Blanco Tract	Zone 68 (Little Egbert Tract)
Roberts Island (Middle, 154/Lower, 106)	Zone 70 (Egbert Tract)
	Zone 76 (Freeport-Franklin)

Note: It is assumed all flooded or damaged islands will be repaired after an event.

Table 10-2 Priority Group Order for Unflooded and Flooded Islands

Priority Group Order – Islands That Are Threatened But Not Yet Flooded	Priority Group Order – Flooded Islands
A1 – Population A (>/= 10,000)	B1 – Flooded Population Areas A & B
A2 – Population B (>/= 5,000)	B2 – Salinity 1
A3 – Salinity 1	B3 – Salinity 2
A4 – Infrastructure A	B4 – Salinity 3
A5 – Population C (>/= 1,000)	B5 – Salinity 4
A6 – Salinity 2	B6 – Salinity 5
A7 – Infrastructure B	B7 – Infrastructure B
A8 – Population D (>/= 500)	B8 – Population C
A9 – Salinity 3	B9 – Population D
A10 – Salinity 4	B10 – Infrastructure D
A11 – Infrastructure C	B11 – Salinity 6
A12 – Infrastructure D	B12 – Salinity 7
A13 – Salinity 5	B13 – Salinity 8
A14 – Salinity 6	
A15 – Salinity 7	
A16 – Salinity 8	

Table 10-3 Population Priority Groups (Islands/Areas in Priority Order)

Population A (>/= 10,000) Zone 196 (South Sacramento/pocket) ***Population B (>/= 5,000 but < 10,000)*** West Sacramento North Zone 157 (Smith Tract, West Stockton) Wright-Elmwood Tract/Sargent-Barnhart Tract (West Stockton) Zone 76 (Freeport-Franklin) Sargent-Barnhart Tract 2 (West Stockton) Discovery Bay ***Population C (>/= 1,000 but < 5,000)*** RD 17 Mossdale (Lathrop Area) Shima Tract (Northwest Stockton) Zone 159 (Boggs Tract, West Stockton) Zone 185 (Northwest Stockton) West Sacramento South 1	***Population C (cont.)*** Zone 158 (Weber Tract, West Stockton) Bethel Island Brannon-Andrus Island SM-124 (Suisun Marsh, SW of Suisun City) Grand Island New Hope Tract Netherlands ***Population D (>/= 500 but < 1,000)*** Hotchkiss Tract Zone 126 (Pico Naglee, north Tracy) Zone 37 (North Shore Suisun Bay near Benicia) Roberts Island (Middle, 154/Lower, 106) Pierson District Terminous Tract Tyler Island 1 Union Island

Table 10-4 Infrastructure Priority Groups (Islands/Areas in Priority Order)

Infrastructure A (Mokelumne Aqueduct, if island is not already flooded)	***Infrastructure B (cont.)***
Orwood	*Hwy 160* (cont.)
Woodward	Brannon-Andrus Island
Jones Tract	Grand Island
Roberts (Middle/Lower)	Sutter Island
Wright-Elmwood/Sargent-Barnhart	Pierson District
Infrastructure B (State Highways)	Zone 148
Hwy 12	Zone 197
Brannon-Andrus	Sacramento Pocket Area (196)
Bouldin	***Infrastructure C (Railroad, if island is not already flooded)***
Terminous	
Hwy 4	
Byron	Boggs Tract (159)
Victoria	***Infrastructure D (Natural Gas Storage and Retrieval)***
Roberts (Middle/Lower)	McDonald Tract
Hwy 160	
Sherman Island	

Table 10-5 Salinity Priority Groups (Islands/Areas in Priority Order)

Salinity 1 (Old River Corridor, South to North)	***Salinity 4 (West Delta)***
Union	Twitchell
Victoria	Bradford
Fabian	Jersey
Coney	Sherman
Byron 2	***Salinity 5 (San Joaquin River – Upstream*** South to North)
Byron 1	Rough & Ready
Woodward	Wright Elmwood
Orwood	Wright Elmwood / Sargent Barnhart
Palm	RD17 Mossdale
Bacon	***Salinity 6 (North Delta)***
Veale	Terminous
Holland	Staten
Hotchkiss	Tyler 2
Bethel	Grand
Quimby	Ryer
Salinity 2 (Middle River Corridor, South to North)	Little Egbert
Roberts (Middle/Lower)	Egbert
Jones	Hastings 2
McDonald	Pierson
Mandeville	Sutter
Salinity 3 (San Joaquin Corridor, Southeast to Northwest)	Netherlands
Ringe	***Salinity 7 (East Delta A)***
King	Brack
Empire	Canal Ranch
Medford	New Hope
Venice	***Salinity 8 (East Delta B)***
Bouldin	Shima
Brannon-Andrus	Bishop
Webb	Rio Blanco
	Shin Kee

Table 10-6 Resulting Island/Area Prioritization

Category A – Unflooded	Category B – Flooded
Sacramento Pocket Area (196)	Sacramento Pocket Area (196)
West Sacramento North	West Sacramento North
Zone 157 (Smith Tract, West Stockton)	Zone 157 (Smith Tract, West Stockton)
Wright-Elmwood/Sargent-Barnhart Tract (191)	Wright-Elmwood/Sargent-Barnhart Tract (191)
Zone 76 (Freeport-Franklin)	Zone 76 (Freeport-Franklin)
Sargent-Barnhart Tract 2 (188)	Sargent-Barnhart Tract 2 (188)
Discovery Bay	Discovery Bay
Union Island 1 (117)	Union Island 1 (117)
Victoria Island	Victoria Island
Fabian Tract	Fabian Tract
Coney Island	Coney Island
Byron Tract 2 (128)	Byron Tract 2 (128)
Byron Tract 1 (127)	Byron Tract 1 (127)
Woodward Island	Woodward Island
Orwood Tract (20)	Orwood Tract (20)
Palm Tract (16)	Palm Tract (16)
Bacon Island	Bacon Island
Veale Tract 2 (129)	Veale Tract 2 (129)
Holland Tract	Holland Tract
Hotchkiss Tract 1 (108)	Hotchkiss Tract 1 (108)
Bethel Island	Bethel Island
Quimby Island	Quimby Island
Jones Tract (Upper and Lower)	Roberts Island (Middle, 154/Lower, 106)
Roberts Island (Middle, 154/Lower, 106)	Jones Tract (Upper and Lower)
RD 17 Mossdale (Lathrop Area)	McDonald Tract
Shima Tract	Mandeville Island
Zone 159 (Boggs Tract, West Stockton)	Ringe Tract
Zone 185 (Northwest Stockton)	King Island
West Sacramento South 1	Empire Tract
Zone 158 (Weber Tract, West Stockton)	Medford Island
Brannon-Andrus Island	Venice Island
SM-124 (Suisun Marsh, Southwest of Suisun City)	Bouldin Island
Grand Island	Brannon-Andrus Island
New Hope Tract	Webb Tract
Netherlands 3 (142)	Twitchell Island
McDonald Tract	Bradford Island
Mandeville Island	Jersey Island
Bouldin Island	Sherman Island
Terminous Tract 2 (87)	Terminous Tract 2 (87)
Sherman Island	Grand Island
Sutter Island	Sutter Island
Pierson District 1 (149)	Pierson District 1 (149)
Zone 148 (E of Sac River near Hood)	Zone 148 (E of Sac River near Hood)
Zone 197 (E of Sac River N of Hood)	Zone 197 (E of Sac River N of Hood)
Zone 126 (Pico Naglee, north Tracy)	Rough & Ready Island
Zone 37 (North Shore Suisun Bay near Benicia Bridge)	Wright Elmwood Tract (190)
Tyler Island 1 (Walnut Grove; 62)	RD 17 Mossdale (Lathrop Area)
Ringe Tract	Shima Tract
King Island	Zone 159 (Boggs Tract, West Stockton)
Empire Tract	Zone 185 (Northwest Stockton)

Category A – Unflooded	Category B – Flooded
Medford Island	West Sacramento South 1
Venice Island	Zone 158 (Weber Tract, West Stockton)
Webb Tract	SM-124 (Suisun Marsh, Southwest of Suisun City)
Twitchell Island	New Hope Tract
Bradford Island	Netherlands 3 (142)
Jersey Island	Zone 126 (Pico Naglee, north Tracy)
Rough & Ready Island	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Wright Elmwood Tract (190)	Tyler Island 1 (Walnut Grove; 62)
Staten Island	Staten Island
Tyler Island 2 (63)	Tyler Island 2 (63)
Ryer Island	Ryer Island
Zone 68 (Little Egbert Tract)	Zone 68 (Little Egbert Tract)
Zone 70 (Egbert Tract)	Zone 70 (Egbert Tract)
Hastings Tract 2	Hastings Tract 2
Brack Tract	Brack Tract
Canal Ranch	Canal Ranch
Bishop Tract	Bishop Tract
Rio Blanco Tract	Rio Blanco Tract
Shin Kee Tract	Shin Kee Tract

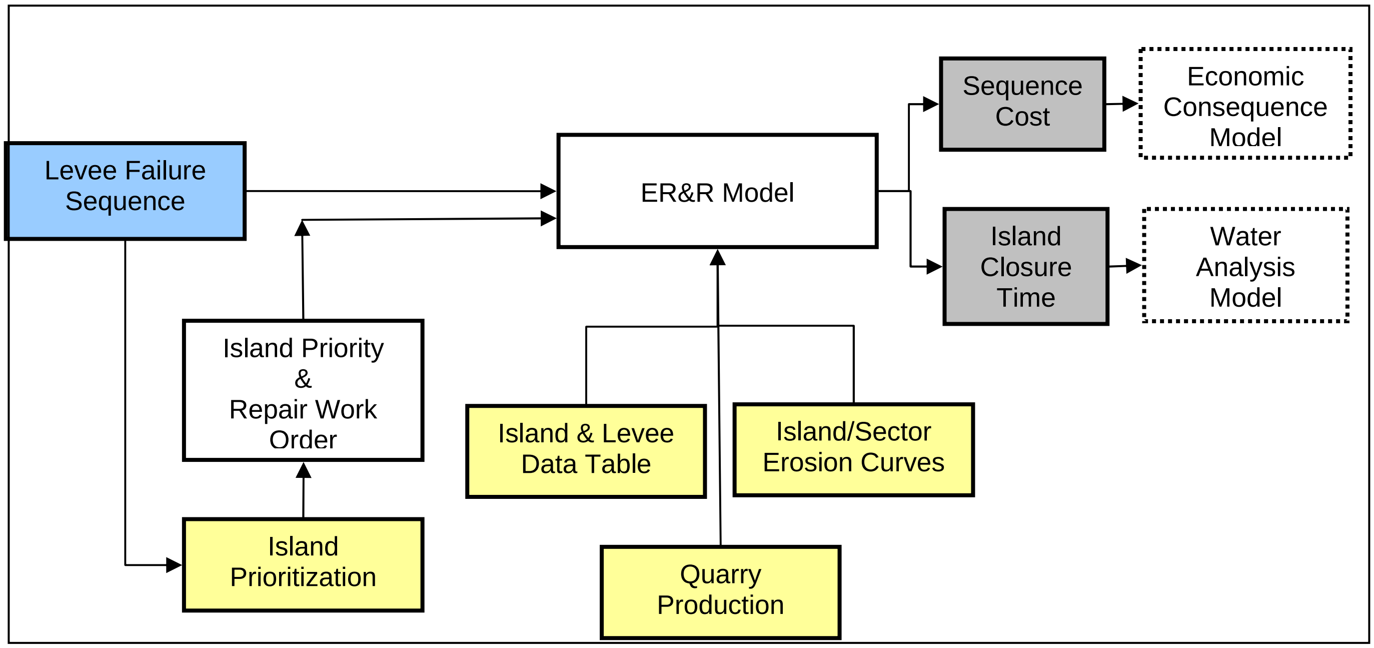

Figure 10-1 DRMS Levee Emergency Response and Repair Approach

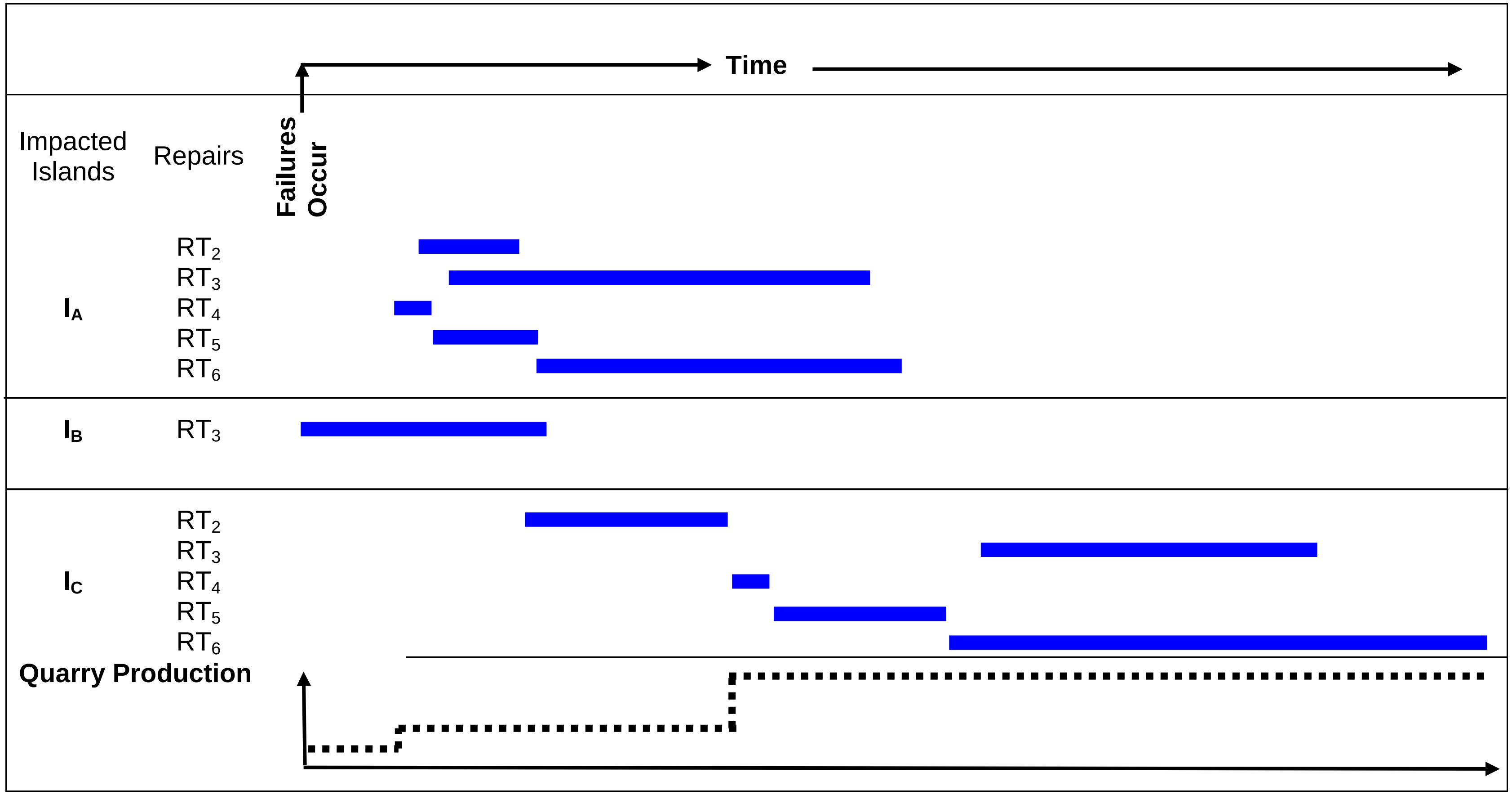

Figure 10-2 Schematic Illustration of the ER&R Model Timeline of Repairs for a Levee Failure Sequence

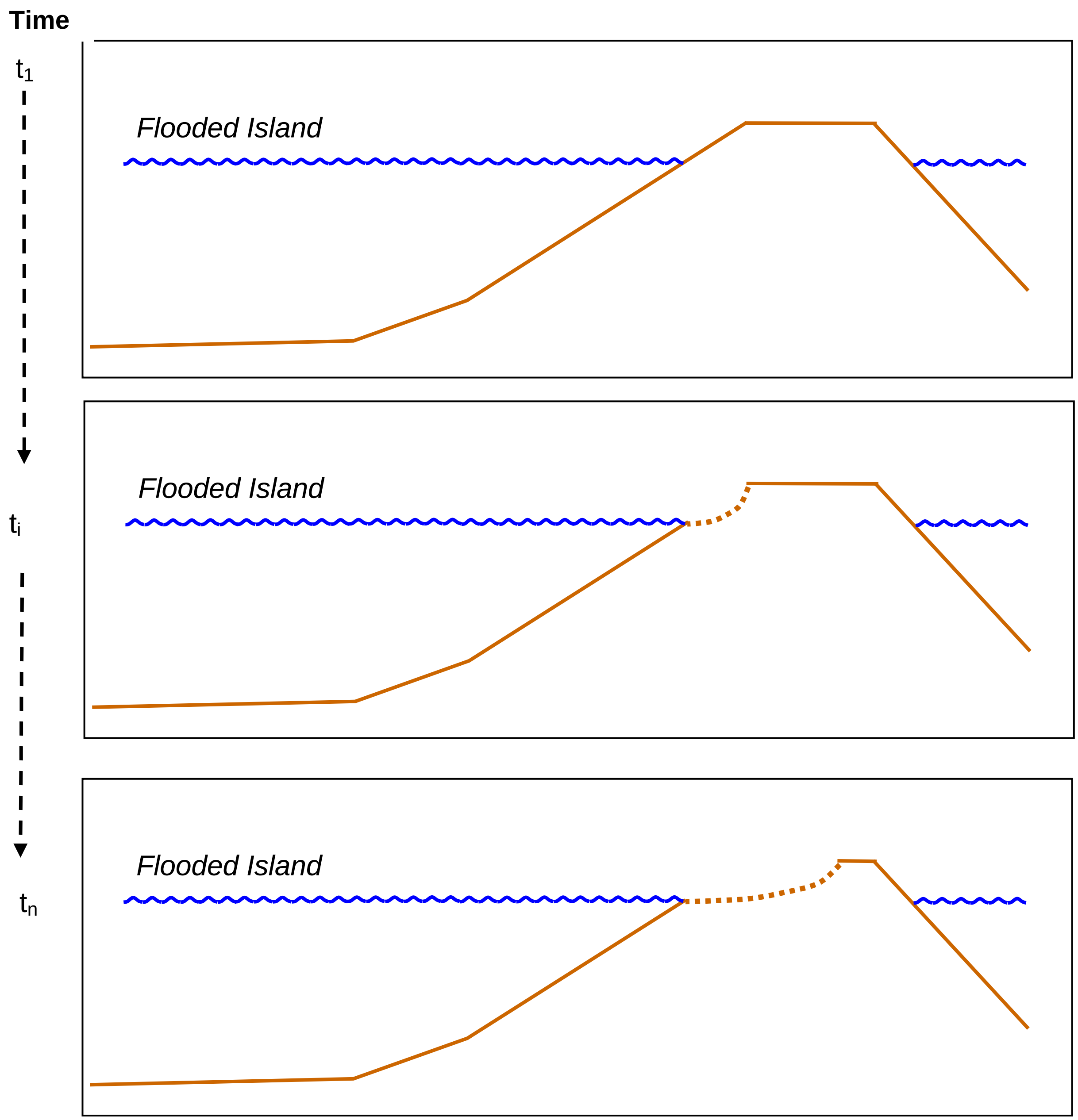

Figure 10-3 Schematic Illustration of the Levee Interior Erosion Model