Rangitaiki River Stopbanks

Review of Stability

Prepared for

Environment Bay of Plenty

September 2005

ICE GEO & CIVIL

A division of ICE CONSTRUCTION LTD

Rangitaiki River Stopbanks

Review of Stability

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Date: 26 September 2005

Status: draft

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1 Introduction

The low-lying Rangitaiki Plains are protected from flooding by a system of stopbanks and canals. The flooding potential of the plains has been made worse by the occurrence of up to 2m of subsidence following the 1987 Edgecumbe earthquake. This has resulted in large areas of land within the plains being close to or below sea level and pumped drainage is required.

A breach occurred in the Rangitaiki River stopbank adjacent to Hydro Road in July 2004. This caused extensive flooding and some areas where under water for up to two weeks. It was concluded following investigations at the breach site that the breach was caused by a piping failure below the stopbank. This was thought to be due to a highly permeable soil layer passing below the stopbank with only a thin covering of low permeability soil in the adjacent paddock.

The July 2004 river flow was the greatest since the stopbanks were built and the breach the first since the stopbanks were repaired following the 1987 Edgecumbe earthquake. Prior to the stopbank breach several areas of seepage and potential heave were noticed along the toes of the stopbanks, mainly within Edgecumbe. Due to the breach and the identification of other potential problem areas, Environment Bay of Plenty (EBOP) have decided to review the stability of all the stopbanks along the Rangitaiki River.

Stopbank flood protection systems can have the following problems:

- Overtopping due to the design flood being exceeded or stopbank subsidence. The design stopbank level is not considered to be part of this review.
- Structural failure under low river, high river or drawdown conditions.
- The formation of pipes in the soil under the stopbank due to the hydraulic gradient being sufficient to remove soil particles. This can result in excessive seepage, undermining and collapse of stopbanks.
- Heave and bursting of surface low permeability soil layers due to high water pressures in underlying high permeability soil layers. This also can result in stopbank collapse.
- Excessive seepage ponding behind the stopbank.

Ice Geo and Civil has been commissioned by EBOP to assess the susceptibility of the Rangitaiki River stopbanks to structural and seepage failures. This has been carried out by reviewing all the available information on the stopbanks, their construction and foundations, to identify potential problem areas in large floods. This report presents the following:

- a discussion on the critical parameters affecting stopbank performance,
- a summary of the known problems with the stopbanks since their construction,

- the results of a questionnaire sent out to landowners along the river banks,
- a summary of the available information on the stopbank geometry,
- a summary of all the available information on the foundation soils close to the stopbanks,
- an assessment of other areas with potential problems and
- a recommended programme for more detailed investigations.

2 Methodology

This stopbank review has largely consisted of a document search to find all the available information on stopbank construction, stopbank geometry, foundation soils, and past problems. In addition to determining potential problem areas in the stopbank system it is hoped that this review will be a useful reference document collating all the available information for use in more detailed studies of particular sections of the stopbanks. Therefore all the information gathered is either presented in this report or referenced.

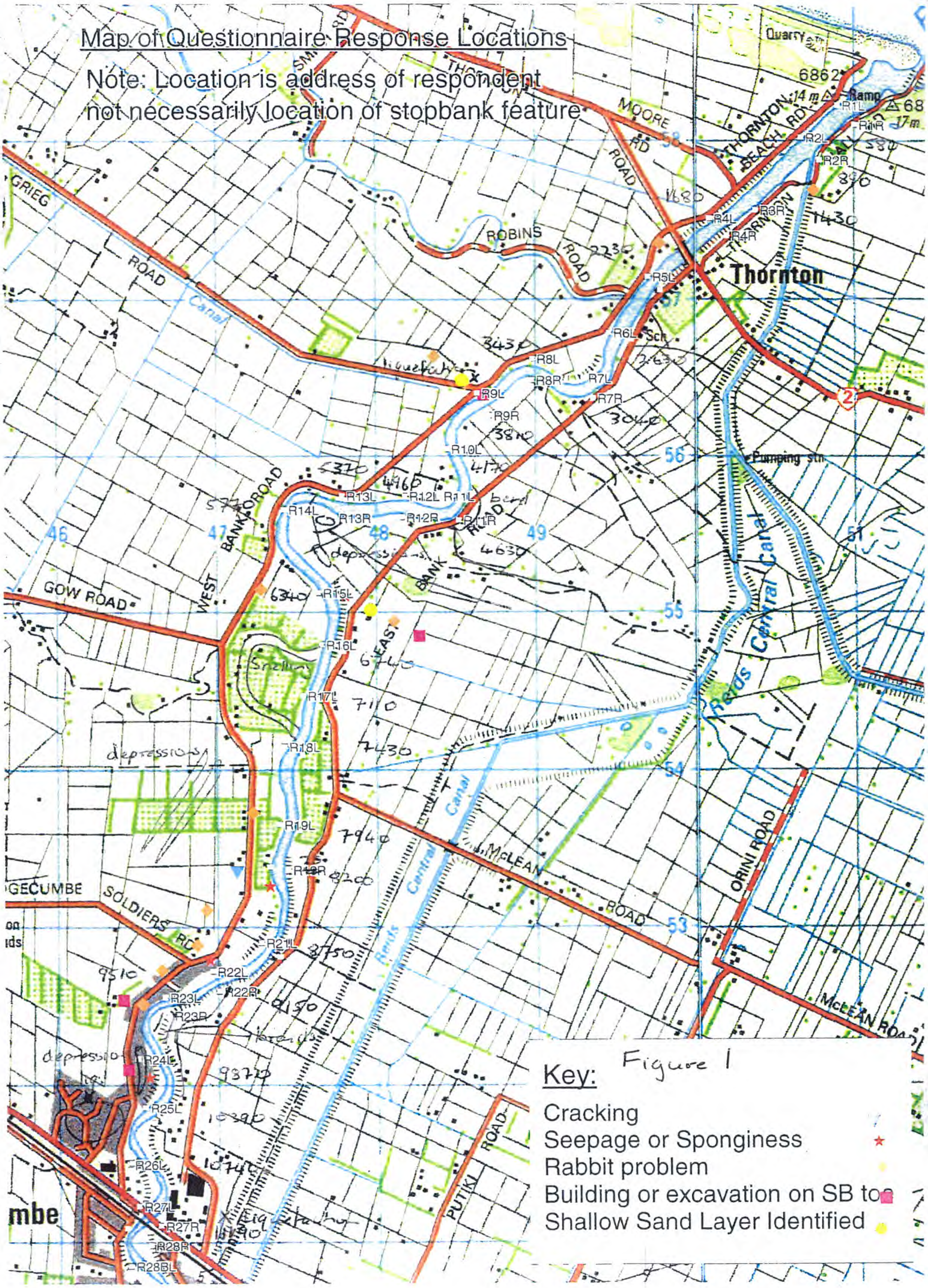
Information was gained from a search of EBOP files on the stopbanks, all the reports produced on the stopbanks listed in the references, old aerial photographs and all the drawings found relating to the stopbanks. A table summarising all the available information on the stopbanks is presented in Appendix A and a list of all the available drawings is given in Appendix B. Appendix C gives a summary table of all the available subsurface soil information and copies of this information.

In order to make the best use of the information an attempt has been made to reference all the information to a distance in metres from the river mouth. EBOP has established a system of benchmarks along the river banks and these have been used as reference points where-ever possible when meterages are not provided in documents. Some drawings had local benchmark systems which were not tied into the main benchmark system and the locations could not be accurately established from other features such as bridges. The early drawings were referenced in terms of miles and chains. These distances have been converted to metres in the summary tables.

It is considered that an effort should be made to tie all future work on the stopbanks into the benchmark system to simplify location identification. Figure 1 is marked up with the benchmarks.

In addition to searching the documented information on the stopbanks an effort has been made to obtain local knowledge from landowners and others who have lived and worked in the area. A questionnaire was sent to 200 locals and the feed back is reported in following sections.

Stopbank breaches can be caused by a structural failure of the stopbank or a seepage related failure. Structural failure usually occurs when the face of the stopbank is too steep and there is no river berm. Appendix A gives the batter slopes of the stopbanks and the width of the river berm where known.



Map of Questionnaire Response Locations
Note: Location is address of respondent not necessarily location of stopbank feature
Thornton
GRIEG ROAD
Canal
ROBINS ROAD
MOORE ROAD
THORNTON BEACH RD
Quarry
Ramp
GOW ROAD
WEST BANK ROAD
EAST BANK ROAD
Reids Central Canal
Pumping stn
McLEAN ROAD
SOLDIERS RD
ORINI ROAD
PUTIKI ROAD
mbe
R1L
R2L
R2R
R3R
R4L
R4R
R5L
R6L
R7L
R7R
R8L
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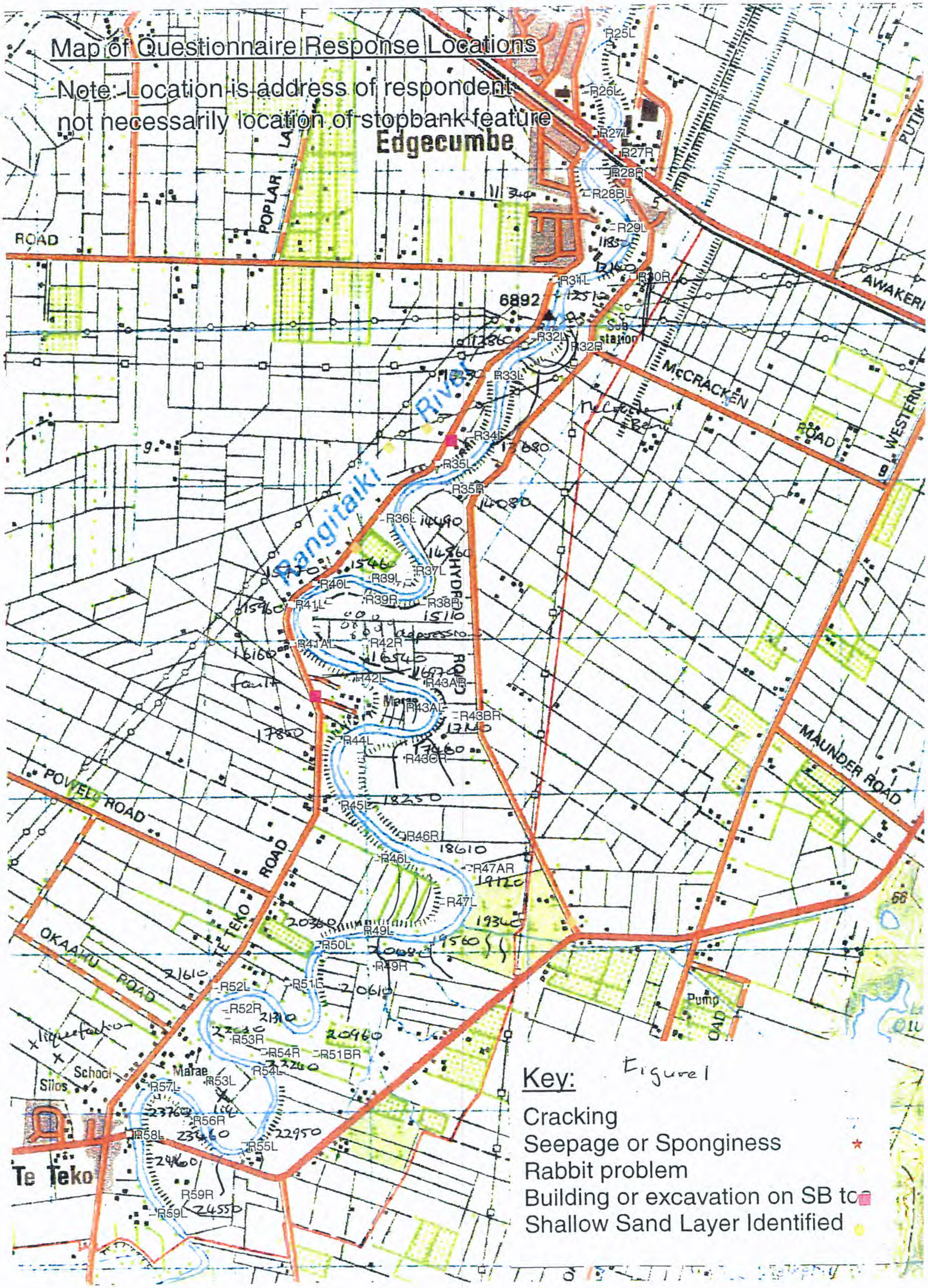
R11R
R12L
R12R
R13L
R13R
R14L
R15L
R16L
R17L
R18L
R19L
R21L
R22L
R22R
R23L
R23R
R24L
R25L
R26L
R27L
R27R
R28R
R28BL
liquefaction
depressions
depression
Figure 1
Key:
Cracking
Seepage or Sponginess
Rabbit problem
Building or excavation on SB toe
Shallow Sand Layer Identified


Map of Questionnaire Response Locations
Note: Location is address of respondent not necessarily location of stopbank feature
Edgecumbe
Te Teko
Rangitaiki River
POPLAR
ROAD
POWELL ROAD
OKAAMU ROAD
TE TEKO ROAD
HYDRO ROAD
McCRACKEN ROAD
MAUNDER ROAD
WESTERN
AWAKERI
Sub station
School
Silos
Marae
Pump
R25L
R26L
R27L
R27R
R28R
R28BL
R29L
R30R
R31L
R32L
R32R
R33L
R34L
R35L
R35R
R36L
R37L
R38R
R39L
R39R
R40L
R41L
R41AL
R42R
R42L
R43AR
R43AL
R43BR
R43CR
R44L
R45L
R46R
R46L
R47AR
R47L
R49L
R49R
R50L
R51L
R51BR
R52L
R52R
R53R
R53L
R54R
R54L
R55L
R56R
R57L
R58L
R59R
R59L
6892
Key:
Figure 1
Cracking
Seepage or Sponginess
Rabbit problem
Building or excavation on SB toe
Shallow Sand Layer Identified

Many failures occur due to drawdown conditions when the river level drops rapidly relative to the water level within the stopbank. The July 2004 flood was a good test on the structural stability of the stopbanks and there was slumping and river bank erosion in many areas. Most of these areas have now been stabilised with rock. The loss of the river berm and the steepening of the stopbank face mean that potential seepage paths have been shortened through these damaged areas. Although there may not have been noticeable seepage problems at these sites during the flood it is considered that these sites should be assessed for potential future problems.

It is considered that failure due to the seepage under a stopbank is more likely than structural failure in areas that have not already been damaged. This stopbank review has therefore concentrated on issues which affect seepage potential such as soil type, length of seepage path and head differential.

3 Parameters Affecting Stopbank Performance

3.1 The Geology of the Rangitaiki Plains

The Rangitaiki Plains are the most northern extent of the Taupo Volcanic Zone on land (Reference 13). They lie in the Whakatane Graben (depressed block of land) with hills to the east, west and south. Geological studies indicate that the graben has been widening at an average rate of 7mm per year with associated small subsidence. The dune system and alluvial lowlands within 10km of the coast have formed in only the last 8,000 years. The plains are therefore geologically very young and unconsolidated which means they are highly susceptible to liquefaction and settlement following significant earthquakes.

The plains have been built up by alluvial deposits settling out of over-bank flows from meandering rivers, wind blown sand, airfall ash deposits and peat formation in depressions. The active volcanism of the upper Rangitaiki River catchment and the high erodibility of the volcanic tephra create a large source of sediment resulting in the rapid growth of the plains. The outcome of the plain formation processes is a wide and unpredictable variety of soil types and grain sizes within small horizontal and vertical distances. Figure 2 (Reference 14) illustrates the floodplain environment of a meandering river with bank erosion and cut-off channels.

A critical soil property for stopbank design is the permeability of the underlying soils. Most of the soils within the plains are silts, sands and gravels with moderate to high permeability. Much of the soil is of pumiceous origin and there are many layers of pumice gravel ranging from lapilli size (up to say 10mm) to cobbles about 100mm in diameter. These layers have very high permeability. A surface layer of more cohesive low permeability silt is found in many areas and this is often the only reason there are not excessive flows under stopbanks. The rapid variation in soil types and layering makes it very

difficult to design a stopbank system which can take into account all possible foundation conditions.

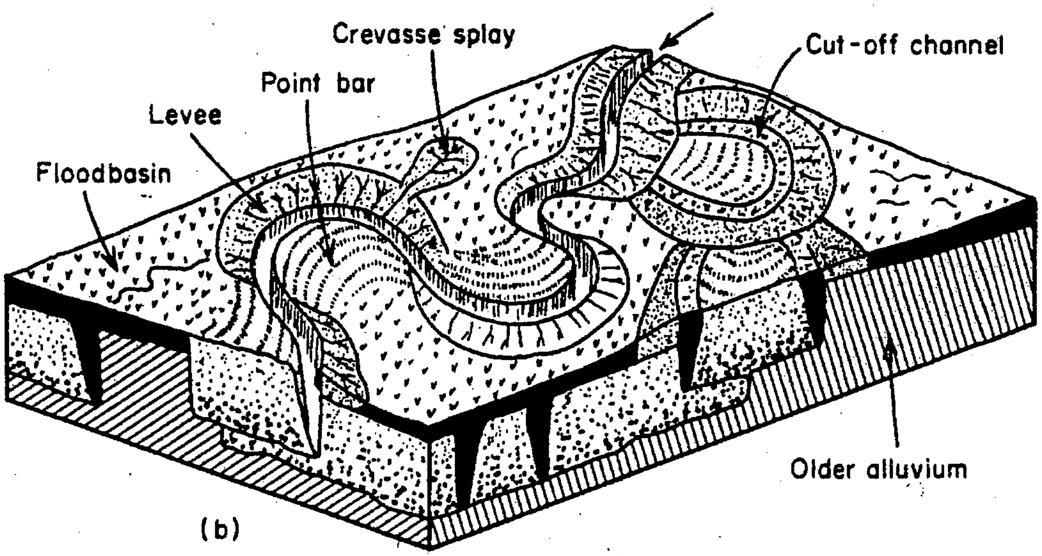


Figure 2: The floodplain environment of meandering rivers (Figure 4.2 Freeze & Cherry (1979) Reference 14)

In addition to the subsurface investigations carried out along the river banks for the initial stopbank construction there have been many other investigations where stopbanks have been raised or there have been seepage problems. This information is useful in determining where there could be high permeability soil layers close enough to the ground surface to cause potential seepage problems under the stopbank. The subsoil information is presented in Appendix C.

3.2 Old Stream Channels

Originally the Rangitaiki River had a branch flowing behind the coastal dunes to the Tarawera River with an outlet at Matata and another branch joining the Whakatane River. This made it possible to sail inland behind the coastal dunes from Whakatane to Matata. The Tarawera branch left the existing river path about 0.5km upstream from Thornton and the Whakatane branch about 2.5km upstream from Thornton. The present Rangitaiki River mouth was excavated in 1914 to aid drainage of the plains. The stopbanks cross these old river branches, the Snelling's and McCracken's bends in the river bed and numerous small tributaries identified from aerial photographs taken in 1944. These old in-filled river and tributary channels can form preferential subsurface flow paths below the stopbanks and have been marked up on Figure 1 and recorded in the summary table.

3.3 River Elevation

As water flows over a river bank coarse grained particles drop out of the water first with progressively finer grains being dropped with increasing distance from the river. This results in natural levees along the river banks and over time the river level rises relative to the adjacent plain. This difference in elevation can be further increased by subsidence of the plains due to drainage. In the period 1950 to 1978 subsidence of up to 4mm a year was recorded. There was another period of rapid subsidence following the 1987 earthquake when there was up to 2m of rapid settlement. This post earthquake settlement is continuing at a reduced rate.

The natural levees along the Rangitaiki River have been raised by stopbanks which prevent the natural plain forming processes. Now the flood water level in the river could be 5m above the adjacent land and any breach in the stopbank allows large volumes to flow from the river. In assessing the seepage potential under a stopbank the slope of the land away from the stopbank has to be considered as well as the height of the stopbank itself. The post 1987 earthquake land contour information has been used to provide the approximate slope away from the stopbanks. This information is included in the summary information table. There are some areas where there is a 2.5m drop in land elevation within 100m of the stopbank toe. Further subsidence may have occurred since the contour plans were prepared.

3.4 Stopbank Construction

Prior to the construction of the present stopbanks along the Rangitaiki River flooding occurred 15 times between 1944 and 1964. During this period some small stopbanks were built by individual farmers. Construction of the present stopbanks was started in the early 1970s with the formation of the low stopbanks along the river downstream of Thornton. These stopbanks required the relocation of buildings and roads. Extensive channel widening was carried out from close to the river mouth to about 2500m. The river and stopbank batters where all formed at 3H:1V using locally won soils. New roads were built along the top of both stopbanks. Attention was paid to removal of the old road pavements and the infilling of drains. Some rock protection was installed on the left bank between 240 and 300m.

The culverts installed through the stopbanks were constructed with large antiseep collars and concrete inlet and outlet structures. Although care seems to have been taken to leave 9 to 14m of river berm beyond the stopbank toe when using the river berm as a borrow area, the outlet drains from the culverts are excavated through the remaining berm to quite close to the stopbank toe. This effectively shortens the seepage path under the stopbank and could create seepage and piping problems if high permeability layers are exposed in the sides of the outlet drain.

Stopbank construction with similar design standards progressed upstream to Edgecumbe in 1972 and Te Teko in 1976. Further work was done between

Edgecumbe and Te Teko in 1978. Care was taken to surcharge the cut off river beds at Reynold's Bend, Snelling's Bend and McCracken's Bend. These surcharges varied from 45 to 130m wide and 1 to 2m thick. Some other isolated hollows were also surcharged. The floodway bypassing Edgecumbe was constructed between about 1977 and 1982. This floodway is not being assessed in this study.

After the original construction phase further depth and width of river berm was removed from many sections along the river to provide fill for the floodway construction. It seems that only 3 to 4m of the berm was left at its original level at the stopbank toe. Some sections of river berm were excavated below water level to provide fill and for river widening. Soil was also removed from the old island at the centre of McCracken's Bend, now Black's farm.

Following the Edgecumbe earthquake extensive lengths of stopbank had to be repaired and later raised by up to 2m to compensate for post earthquake subsidence. In some places batters steeper than 3H:1V were used to reduce the amount of fill required. As before, much of the fill was won from the river berms with another layer of soil removed right up to the stopbank toe, including all that was left at the original river berm level. Therefore in places such as the right bank upstream from Edgecumbe the river berm has been used as a borrow three times. Any low permeability surface silt layers that accumulated on the berm in small floods have been removed leaving direct river water access to high permeability layers at the toe of the stopbank. In addition to this shortening of the seepage path the head differential across sections of the stopbank has significantly increased due to the need to lift the stopbanks following the earthquake.

In more recent years the stopbanks have been raised a little between Edgecumbe and Thornton mainly due to a revision of the design flood. Over these lengths fill was also sourced from the river berm but tests and analyses were carried out to try to avoid the creation of seepage problems and river berm excavation was carefully controlled.

Where the stopbank has been constrained between the riverbank and a road the stopbank batters have been steepened or a concrete floodwall used. This could lead to problems with short seepage paths in some areas. Some toe drains have been installed along lengths of road to reduce the potential for piping and heave.

4.0 Past Problem Areas

4.1 Before the Formal Stopbank System

Prior to the construction of the present stopbanks there were some problems with the more informal stopbanks. In 1962 a blow out occurred in Reynolds Bend (about 3400m RB). This was considered to be a piping failure that originated in a paddock 50-60 yards from the stopbank. In 1964 during

another flood there was another blow out at Thornton. Both of these failures occurred in areas where there is a significant drop in ground level away from the stopbank. In 1968 the stopbank was overtopped in Hydro Rd.

4.2 Following Stopbank Construction

Seepage areas identified after construction of the existing stopbanks were remedied by toe loading and surcharges. Following the 1987 earthquake the ground near the Thornton School (2600m RB) subsided and a spring emerged 250m from the river. Investigations showed an old river channel in this area and a coarse sand and pumice aquifer. It was concluded that the spring was not directly related to the river but that there was a low factor of safety against a heaving failure. A 0.5m thick overlay was recommended.

Investigations carried out in 2002 for the raising of the stopbank on the right bank between Edgecumbe and Thornton identified a highly erodible silt layer at around 4900m. Sinkholes had developed in this area and it was considered that this could be due to silt being transported through adjacent layers of coarse sand or gravel.

4.3 1987 Earthquake

A total of 5940m of stopbank along the Rangitaiki River was damaged by the March 1987 Edgecumbe earthquake. This damage included slumping of the riverbanks and stopbanks, and stopbank cracking due to the earthquake accelerations and the loss of strength of stopbank foundations. It was noted that there was some correlation between the loss of strength of the stopbank foundations and the placement of toe loading and surcharges to reduce flow under the stopbanks. Culverts and pumping stations were also damaged. The immediate repairs were completed by October 1988. The fault rupture crossed the river at 16160 to 16970m.

In addition to the immediate repairs carried on the stopbanks the stopbanks had to be lifted as up to 2.05m of settlement occurred in the area around Edgecumbe, significantly changing the grade along the river. The earthquake resulted in up to a 3m change in water level measured in some bores and many springs developed across the plains. Some of these springs continued to run weeks after the earthquake. The drop is ground level and the activation of springs is an indication of liquefaction of subsurface sands and silts. Liquefaction is an indication of the absence of fine clay particles which bind soil grains together. Therefore these soils are also likely to be susceptible to piping, that is the removal of soils grains by water flow and the formation of holes through soil layers. The soils may also have medium to high permeability.

The earthquake damage rating system used by the Bay of Plenty Catchment Commission is given in Table 1.

Table 1: Earthquake damage rating system (from reference 4)

Damage Type	Description
I	River bank slumping on narrow berm areas where other structures are affected.
IA	As I with stopbank damage.
IB	As I with concrete wall foundation failure.
IC	As IB with concrete wall failure.
II*	Failure of surcharge area which was constructed to prevent piping beneath the stopbank. This area has highly permeable sand layers underneath which liquefied during the earthquake, causing sand boils and settlement. Much of the fill is also extensively cracked.
III	Slumping of the berm banks into the river.
IV	Faultline rupture across the stopbank.
V*	Severe longitudinal cracking of the stopbank. Cracks larger than 75mm.
VI*	Isolated transverse cracking of stopbanks where cracks are 100mm wide or greater. (cracks up to over 2m deep)
VII	River bank slumping away from stopbank with trees falling into the river.
VIII*	Lightly cracked stopbank areas with cracks up to 75mm in width.
IX	Cracking of berm areas within 20m of the stopbank toe.
X	Existing protection works slumped into the river.

The damage types marked with an asterix are of particular interest for this study of stopbank stability as they could indicate soil layers susceptible to piping or with medium to high permeability. The damage ratings have been included in the stopbank information summary table as an indication of soil type.

4.4 July 1998 Flood

The flood of 11 to 14 July 1998 was the first to rise above the river berms since the stopbanks were rebuilt following the 1987 earthquake. The river level rose to about 1.5m below the stopbank crests. Five lengths of stopbank seepage were identified within Edgecumbe township, Miro Place at the railway bridge (11600m RB), Ngaio Place at the Fertiliser Works (11800m LB), the Transpower Substation at Hydro Road (12500m RB), Anchor Products (Fonterra) (11000m RB) and College Road (10400m LB). The first

three lengths were protected by toe buttressing with rock or sand bags. At the substation the emergency work consisted of two buttresses 75m long, 10m wide and 1.5m high.

At College Road there is a 1.4m high floodwall along the top of the stopbank and a 1m high wall along the side of the road. The stopbank is therefore relatively narrow compared to its height and the seepage paths through and under the stopbank are reduced compared to adjacent sections.

At Anchor Products the seepage was found to be largely related to the construction of a crib wall along the inland toe of the stopbank and the penetration of up to nine pipes through the stopbank.

Some distance from the stopbank around Ngaio Place, sand boils, springs and areas of soft ground were observed. These were possibly the result of sand boils or fissures due to the 1987 Edgecumbe Earthquake producing preferential seepage paths. A hole formed in the turning circle at the end of Ngaio Place possibly due to heave under the seal.

Seepage was also observed 100 to 150m away from the stopbank along Nikau Rd.

Investigations were carried out by Opus International Consultants and the analyses suggested that there could be stopbank failure at the Anchor Products and College Road sites in flood conditions. Possible internal erosion problems were also identified at the Ngaio Place and Transpower sites. Possible piping problems consistent with the site observations during the flood were identified by the analyses at the Miro Place, Ngaio Place and Transpower sites. The Anchor Products section has been stabilised by the addition of further drainage and a buttress and drainage has been used to improve the stability of the College Road section and at the substation. Pressure relief wells were also recommended for Miro Place, Ngaio Place and areas of College Road further away from the stopbank.

During this flood locals also observed spongy ground within the old McCracken's Bend island.

4.5 July 2004 Flood

The most significant effect of the July 2004 flood was the stopbank breach on the right bank at 13200m, just upstream from Edgecumbe. The causes of this breach are discussed in detail in reference 15. It is considered to have started in the paddock 50 to 60m from the toe of the stopbank with a rapid piping failure leading back to the stopbank. An aerial photo taken in 1944 shows a tributary stream and possibly a low lying swampy area in this paddock. The failure may have originated in either of these locations.

Following the flood a condition assessment was carried out by EBOP on the stopbanks from 9300m to 24200m. The data recorded is included in the

stopbank information summary. The following areas of concern were identified:

Left bank

- At 13920m there was minor erosion along a narrow river berm and no erosion protection.
- There is no river berm at 14470m.
- There is no river berm on the outside of the bend at 16130m.
- On the outside of the bend at 17940m there is no river berm.

Right bank

- At 9470m there is a drain along the inland toe of the stopbank which could cause seepage and piping problems.
- There is no river berm or erosion protection on the outside of the bend at 10950m.
- There were more problems with excessive seepage at the Fonterra site at 11200m and some river bank slumping. An unblocked culvert below the stopbank was found to have caused the problem. Repairs have now been carried out.
- Along the outside of the bend from 14980 to 15140m there is either no river berm or an eroding narrow berm and no erosion protection.
- A negative freeboard was found at 23510m.

As discussed previously much erosion protection work has been carried out since this inspection.

During the repairs to the breached area at 13200m the thickness of the low permeability surface layer in what remained of the paddock was investigated. As a result an overlay was placed in some areas.

Reports were received of spongy ground within the old McCracken's Bend island where fill had been removed for the construction of the floodway. Investigations were carried out here and another overlay placed.

During the breach investigation it was found that there was an amount of local knowledge about the response of the ground behind the stopbanks to flood levels in the river. It was therefore decided that local knowledge should be sought as a preliminary phase of a study into the integrity of the stopbanks along the Rangitaiki River. A questionnaire was sent out to 200 landowners and lease holders along both sides of the river and rural contractors who work in the area. The results of this questionnaire are presented in the following section.

5 Information from the Public

5.1 The Questionnaire

A copy of the questionnaire and the information sent out with it are included in Appendix D. People were asked to comment on:

- Whether they had observed any seepage or sponginess in the paddocks behind the stopbanks when river levels are elevated. This is an indication of high permeability layers which pass below the stopbank and are close to the ground surface.
- Whether they had observed any water coming up around posts or poles or movement in posts or poles. In previous floods water has been observed coming up around power poles some distance from the river. This is considered to be due to the pole penetrating to a highly permeable layer. If the water flow is sufficient to wash soil particles out, high water flows and possibly stopbank collapse could result.
- If they had noticed sand layers close to the ground surface during their normal farming activities.
- Whether there were any rubbish pits or other excavations closer than 100m to the stopbank. These can lead to a short circuit in seepage paths under a stopbank and eventually failure.
- Whether they had a rabbit problem. Rabbits like to burrow in stopbanks above the high winter ground water level. If the rabbit holes are extensive they could significantly shorten the seepage path.
- Whether they knew of any pipes through their section of stopbank. A seepage path could develop along the outside of pipes installed without proper compaction or seepage collars.
- Whether they had observed any cracks in the stopbank.

5.2 Questionnaire Responses

A total of 27 responses were received. Each questionnaire form was numbered so that there was no confusion about the location of the respondent. Many of the respondents had not observed any of the conditions detailed. Table 2 summarises the results of the responses received. The approximate locations of the condition are given in terms of distance in metres from the river mouth.

Discussions were held with 10 of the respondents and site visits made to eight of them. It can be seen from the table that the rabbits were the most common condition reported. The reports varied from one or two rabbits to many. They are reasonably well spread down the length of the stopbanks. The lower number of reports on the right bank may be due to there being fewer landowners on this side of the river.

The most concerning reports are those of seepage or sponginess behind the stopbanks. These sites have been visited and are discussed in following sections.

Table 2: Questionnaire responses

Condition	**Responses**	
seepage/sponginess	9100LB 10390LB 16500LB	6000RB
seepage from post/pole holes	nil	
shallow sand layers	4000LB	
excavations close to stopbank	4000LB 16500LB	6000RB 16000RB
rabbits	2200LB 4000 LB 6400LB 7900LB 8700LB 10000LB 16500LB	900RB 6000RB 9500RB
pipes through stopbank	4000LB 7900LB 16500LB	16000RB 16800RB
cracks in stopbank	nil	

5.3 Discussion of Responses

5.3.1 Right Bank 6000m

The farmer at this location, and his downstream neighbour, have problems with seepage well away from the stopbank when the river is high. Old aerial photographs of this area suggest some depressions close to the river bank. At present the ground slopes down to about RL0.5 within say 150m of the landward stopbank toe. The crest of the stopbank is typically RL4.6. When the river is high there is therefore a considerable head difference between the river water level and the low lying ground. Some subsurface drainage has been installed by the farmers to reduce surface pugging but the central area between the river and East Bank Road remains very wet in winter. It is not exactly clear whether the wetness is due to seepage from the river or is just due to the low lying nature of the area.

In the 1987 earthquake this section of stopbank suffered transverse cracking with cracks over 100mm wide. This type of damage could be due to liquefaction and loss of strength of foundation soils. The soils which have this type of response to earthquake loading could also be readily erodible and/or have high permeability.

The farmer also noted that he had lost about 5m width of river berm within 12 months. The berm was lowered to win fill to raise the stopbank in 2002. In the location of the failure the river bank consists of fine sand. Investigations carried out in 1973 showed 3.3m of silts and silty sand overlying medium sands at 30m from the river bank. This is consistent with investigations carried out in 2002 which showed 2.6m of silt and silty sand over medium sand close to the stopbank centreline. In the river berm the depth to medium sand was found to be 2.7m. During the recent stopbank raising programme care was taken not to expose highly permeable layers by river berm excavation.

In most cases the 2.6 to 3.3m depth to a high permeability layer would be considered to be sufficient to prevent excess seepage, piping and heaving problems. However due to the ground falling away from the stopbank at this site it is considered that closer investigation is required.

During willow clearing some years ago the cleared trees were buried in holes in the river berm. This was noted by several farmers. At this site the trees have been removed and the holes backfilled.

5.3.2 Left Bank 9100m

This site is a residential section on College Road in Edgecumbe. At this location the top of the stopbank is at about RL6.1 and the level of the residential properties is about RL4.4. There is no river berm and the back boundary of the properties is at the toe of the stopbank. The landward batter of the stopbank is at 3.2H:1V and on the river side the batter is 3.6H:1V. The horizontal distance from the river bank to the property boundary at typical ground level is only 15m. The river cross section at this location shows some deepening of the river bed on this side of the river. A small slump in the river bank has developed opposite this property.

The resident reported that the ground was spongy and the paving stones at the back of the house lifted during the July 2004 flood. Following the flood some of the paving stones and the corner of a deck have sunk. During the flood the water is said to have been lapping at the top of the stopbank before the stopbank failure upstream. The residents had not noticed any sponginess or seepage in floods before 2004.

It is considered that the sponginess observed at the site was due to high water pressures developing beneath a surface low permeability layer. The subsequent settlements could be due to cohesionless layers settling back

down in to a denser state as the water pressures dissipated or due to the loss of soil. No dirty water indicating loss of soil was observed by the residents. It is likely that there remained high water pressures in the ground when the earthquake swarm of 18 July 2004 occurred. The vibrations caused by the earthquakes could have contributed to the densification of cohesionless soils.

It is considered that the potential heave at this and neighbouring properties should be investigated. The confined nature of the sites will make any remedial measures difficult. The short distance to the river bank could result in high flows from pressure relief systems if there is a high permeability layer close to the ground surface.

5.3.3 Left Bank 10390m

This is another residential property on College Road within Edgecumbe. It is the first property next to a section of stopbank with a concrete flood wall and toe wall due to a lack of space between the river and College Road. The top of the stopbank at this property is at RL6.9, about 2m above the adjacent ground level. The river cross section at this point does not extend down to the adjacent ground level. The river berm was eroded away during the July 2004 flood and rock rip rap has been placed to prevent further erosion. The water level was up to the top of the stopbank during the flood and the occupants were evacuated. The river berm in this area slumped in the 1987 earthquake. This could be due to the steepness of the river bank on the outside of a bend and/or the presence of low strength cohesionless soil layers.

During the July 2004 flood the property was covered in water to about ankle deep It is not clear whether the water was due to surface ponding or due to seepage from under the stopbank, however the front lawn was described as being like jelly to walk on. This suggests high water pressures under the upper soil layers.

Some erosion occurred under a concrete slab at the back of the property forming a hole about 300mm deep. Repairs had been carried out before the questionnaire was sent out. It is possible that the erosion was caused by seepage flow under the stopbank being concentrated at the point of least resistance. Alternatively there is a possibility that the erosion was caused by surface water flow into a nearby stormwater drain.

Now that the river berm has been eroded away the seepage path to the back of the property is quite short. The fact that there appears to have been high water pressure under the front lawn as well as the back suggests that there is a highly permeable layer extending under the house. Seepage under the concrete wall just upstream from the property was a problem in the flood in 1998. Investigations showed layers of sandy fill, silt and peat with coarse sand at 7.0m depth. Due to the short seepage path the sandy layers appeared to have enough permeability to cause a seepage problem and a toe drain was recommended and has been constructed.

The house is on short timber piles and some movement has been noticed after the 2004 flood. As for the house at 9100mm this could be due to densification of cohesionless soil layers. Early aerial photographs suggest a depression or old river channel at this site. The older residents recall a river channel along what are now Kowhai St and Rata Road. This is another reason for suspecting a high permeability cohesionless layer below ground level.

5.3.4 Left Bank 16500m

This section of stopbank is around the Kokohinau Marae and is where the 1987 fault rupture crossed the river. It is considered that the ponding reported on this site near the urupa is due to subsidence along the line of the fault and not due to seepage under the stopbank. This subsidence is on-going 18 years after the earthquake. During the July 2004 flood people from the marae carried out regular inspections along the stopbank and they did not observe anything that could be attributed to seepage.

There was a rubbish pit close to the stopbank, but this has been filled in. There is one concrete culvert with a flapgate through the stopbank which was installed during stopbank construction. There is also a 300mm diameter corrugated steel pipe with a flapgate through the stopbank in the paddock downstream of the marae. The inland end of the pipe is bent and it appears to be blocked. No one at the marae can remember it being used.

Some small areas of subsidence about 1m wide have occurred at the marae near the kitchen. These do not appear to be due to leakage from any pipes or related to trenching. The holes have been backfilled when they occur. It is possible that the holes are formed as buried tree stumps close to the ground surface rot away. Many stumps are exposed in the river bed and banks just upstream from the fault rupture and the farm on the opposite bank has similar problems. It is possible that if the rotting stumps extend through to a highly permeable layer they could create a short circuit in the seepage path from the river bank.

5.3.5 Left Bank 4000m

The stopbank along this length of the river has recently been raised. It remains only 1.2m above the natural ground level and has a timber retaining wall on the inland side due to it being constrained between the river bank and a driveway. There is a gravel drain along the toe of the wall.

The main concern here was a pipe through the stopbank which drains a cattle stop. A hole had developed around the outside of this 100mm diameter PVC pipe. At the design flood level there would be about 1.5m head at the pipe level. The hole around the pipe has now been repaired and a non return valve fitted. There is another pipe through the stopbank from a catchpit on the drive. This pipe has also been inspected.

A fine sand layer has been exposed about 1m below the ground level in a silage pit excavated some distance from stopbank. No seepage has been observed coming through the sand layer. Due to the low height of the stopbank and the distance of the excavation from the stopbank, it is not considered that the sand exposure will cause unacceptable seepage problems.

5.3.6 Right Bank 16000m

As at 6000m willow trees were buried in several holes along the river berm around this bend in the river. The river berm is typically 50m wide here and the stopbank is about 4m high. The ground does not fall away behind the stopbank and no seepage has been observed in the paddocks. However it is considered that the buried willows should be removed and the holes filled with fine grained low permeability material.

There are several concrete pipes passing through the stopbank around this bend. They were installed when the stopbank was built and the flapgates are regularly maintained.

5.3.7 Left Bank 7900m

The owner here reported some pipes and a power cable installed through the stopbank to provide water for kiwifruit irrigation. These were installed with cut off collars. The pipes were blocked off and abandoned when repairs were carried out after the 1987 earthquake as kiwifruit growing had been abandoned.

There had been a rabbit problem on this property but the owner had recently gassed the rabbit holes.

5.3.8 Right Bank 16800m

The farmer here reported many pipes through the stopbank. There are four concrete pipes installed when the stopbank was built with functioning flapgates. One pipe drains a small stream which flows for about half the year. There are also several 50mm alkathene pipes feeding water troughs. One pipe runs along the inland toe of the stopbank about 300mm below ground level. These were installed about 20 years ago and there does not appear to have been any seepage problems associated with them.

The fault rupture passes through this property (opposite the Kokohinau Marae) and there are many large stumps exposed in the river bed by erosion across the fault scarp. Following the July 2004 flood there was extensive scour caused largely by eddies around the stumps. Rip rap placed following

the 1987 earthquake was dislodged. Some of the stumps have now been removed and rip rap protection placed along the river bank.

There is an ongoing problem with holes appearing in the river berm and the paddocks across the farm. Early aerial photographs suggest many small depressions in the paddocks within this bend in the river so the problem is not a recent one. It is considered that these holes are due to the rotting of the stumps and collapse of the soil above. The holes appear at a rate of about two to three a year. The farmer fills them in as they appear. As discussed earlier these holes could create a preferential seepage path, however it is considered that the only practical solution is to fill in the holes as is being carried out.

5.3.9 Left Bank 8800m – Edgecumbe Go-cart Track

No questionnaire was received back for this area but there had been reports of large numbers of rabbit so an inspection was carried out. Although no rabbit damage could be found there is a rubbish pit excavated close to the inland side of the stopbank and what appears to be a long drop toilet (or possibly into a septic tank) at the stopbank toe. This information has been passed on to EBOP to investigate.

The stopbank is only about 1.5m high, the ground falls away gently and there was no damage reported here in the 1987 earthquake. There is no subsurface information available from in this area.

6 Assessment of the Stopbank Information Summary

6.1 Assessment Method

All the information in the stopbank information summary presented in Appendix A has been reviewed to try to identify any potential problem areas not identified by a questionnaire response or past known problems. Particular note was taken of the following:

- The height of the stopbank combined with the fall away from the stopbank over 100m.
- The width or absence of a river berm.
- The type of earthquake damage.
- The use of the river berm as a borrow area.

Once potential problem areas were identified, such as those with a combined head of 4 to 5m, a check was made for the availability of any soils information. If there was no information or the available information confirmed the presence of sand layers close to the ground surface, the section of stopbank has been considered worthy of closer investigation.

A total of 4800m of stopbank have been identified as requiring further investigation.

6.2 Left Bank

6.2.1 9100 to 9300m

This section within the urban area of Edgecumbe was also identified by the questionnaire response which described spongy ground. The critical aspects are the height of the stopbank combined with a 1.5m fall away from the river, the lack of a river berm and some erosion. The lateral extent of the investigation of this section may have to increase.

6.2.2 10300 to 10400m

This section was also identified from the questionnaire and has the same critical aspects as that above except that erosion protection is in place. Investigations may have to extend northwards.

6.2.3 11200 to 11500m

This section is just upstream from the road and rail bridges in Edgecumbe. Significant lateral spreading into the river occurred here during the 1987 earthquake indicating liquefiable soils. There is no river berm and the combined head 100m away from the stopbank is over 4m.

6.2.4 11500 to 12200m

Problems were identified with heaving here in the July 1998 flood and again in the 2004 flood. A 1m surcharge was placed here soon after stopbank construction. Opus made recommendations for remedial work after the 1998 flood but this has not yet been carried out. It is considered that this work should be discussed with Opus and actioned.

6.2.5 12200 to 12700m

This section of stopbank is confined between the river and the road, there is no river berm and a combined head of about 4.5m 100m from the stopbank toe.

6.2.6 13000 to 13500m

Type VIII earthquake damage occurred here in 1987 and there is no river berm. There is also a pylon close to the stopbank toe.

6.2.7 17800 to 18000m

The river berm was eroded away here in 2004 and rock rip rap was placed. Some investigations were carried out after a tomo was found in the river face

of the stopbank. The cause of the tomo could not be found but some possible piping problems were identified and there may be some stability issues with the stopbank which now has a front face at 1.9H:1V.

6.3 Right Bank

6.3.1 2900 to 3200m

This section of stopbank is quite low but it contains a floodwall and there is a 2.5m fall within 100m. The available subsurface information shows sand close to the ground surface.

6.3.2 4800 to 6000m

The area between Thornton and Edgecumbe was reasonable comprehensively assessed when the stopbanks were raised in 2003 to increase the flood carrying capacity. The river berm along this section appears to have been significantly eroded since the stopbank was built in 1973 so that now there is no river berm along a significant proportion of the stopbank. Investigations carried out in 2002 resulted in riprap being placed along the river bank to improve stability at 3960 to 4010m, 5360 to 5410m and 5970 to 6070m. The possibility of heave was also identified at 5990m if the fine sand layer below the surface silts has a high permeability. The seepage area identified by the farmer existed before the work done in 2003 and is further from the stopbank than the testing previously carried out. It is therefore considered that further investigation of this area is required.

6.3.3 8950 to 9100m

This is a localised area where the stopbank is close to the road and there is a 2.5m drop in ground level within 100m.

6.3.4 11850 to 12300m

The areas on both sides of the road and rail bridges at Edgecumbe suffered significant lateral spreading during the 1987 earthquake and the stopbanks have had problems with excessive seepage and heave. Drainage and other stopbank protection measures have been installed along the stopbanks on both sides of the bridges. Similarly the next section upstream from 11850 to 12300m has had stopbank buttressing and drainage work and beyond that is McCracken's Bend and the Sullivan's Breach site. The 11850 to 12300m section has little or no river berm, steep stopbank batters (as steep as 2.1H:1V) and a combined head of up to 4.5m. Type V earthquake damage was experienced over part of it. It is therefore considered that investigations are required here.

6.3.5 13600 – 13800m

Old aerial photographs suggest that a braid in the river bed crosses beneath the stopbank at about this section. There is a 15m wide river berm but no evidence of a surcharge being placed in the old channel. The combined head is 5.0m and there was type VIII earthquake damage here

6.4 Rabbits

Rabbit burrows can cause a problem if they extend through a stopbank or far enough into it to significantly shorten seepage paths. Whether rabbit burrows extend from one side of a stopbank to the other can be tested by blowing smoke into a rabbit hole, but smoke tests will not identify how far into a stopbank the burrow goes. It may be possible to examine the extent of burrows using a closed circuit TV system. Discussions have been held with the Department of Conservation about the camera systems they have developed for their own use. They may be able to provide a camera to EBOP or a local contractor to use for rabbit burrow investigations. The camera would have to be bought as there are issues with contamination when being used for native wildlife. It is considered that this possibility should be explored and some representative rabbit burrows investigated to determine how big the rabbit burrow problem could be.

7 Recommendations

It is recommended that further investigations of the sites discussed in Section 6 be carried out in the following order of priority.

1. 10300 – 10400m LB
2. 9100 – 9300m LB
3. 11500 – 12200m LB (in conjunction with Opus)
4. 4800 – 6000m RB
5. 11200 – 11500m LB
6. 11850 – 12300m RB
7. 17800 – 18000m LB
8. 13000 – 13500m RB
9. 13600 – 13800m RB
10. 12200 – 12700m LB
11. 2900 – 3200m RB
12. 8950 – 9100m RB

The following should also be carried out.

- Confirmation of the depth and soils exposed in the rubbish pit at the Edgecumbe go-cart track and the presence of the suspected toilet.
- Removal of the willow trees buried in the right bank river berm at around 16000m.
- Investigation of the depth and extent of some rabbit burrows.

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