on Ground Water Management in New Zealand

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Minnesota Ground Water Association Conference, St. Paul, MN
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Global Position

~ 8,000 nautical miles south west of Minneapolis-St. Paul

~35-46 S Latitude, 176-178 E Longitude

19 hours time difference

Political Status

1840- Treaty of Waitangi- NZ became British Colony

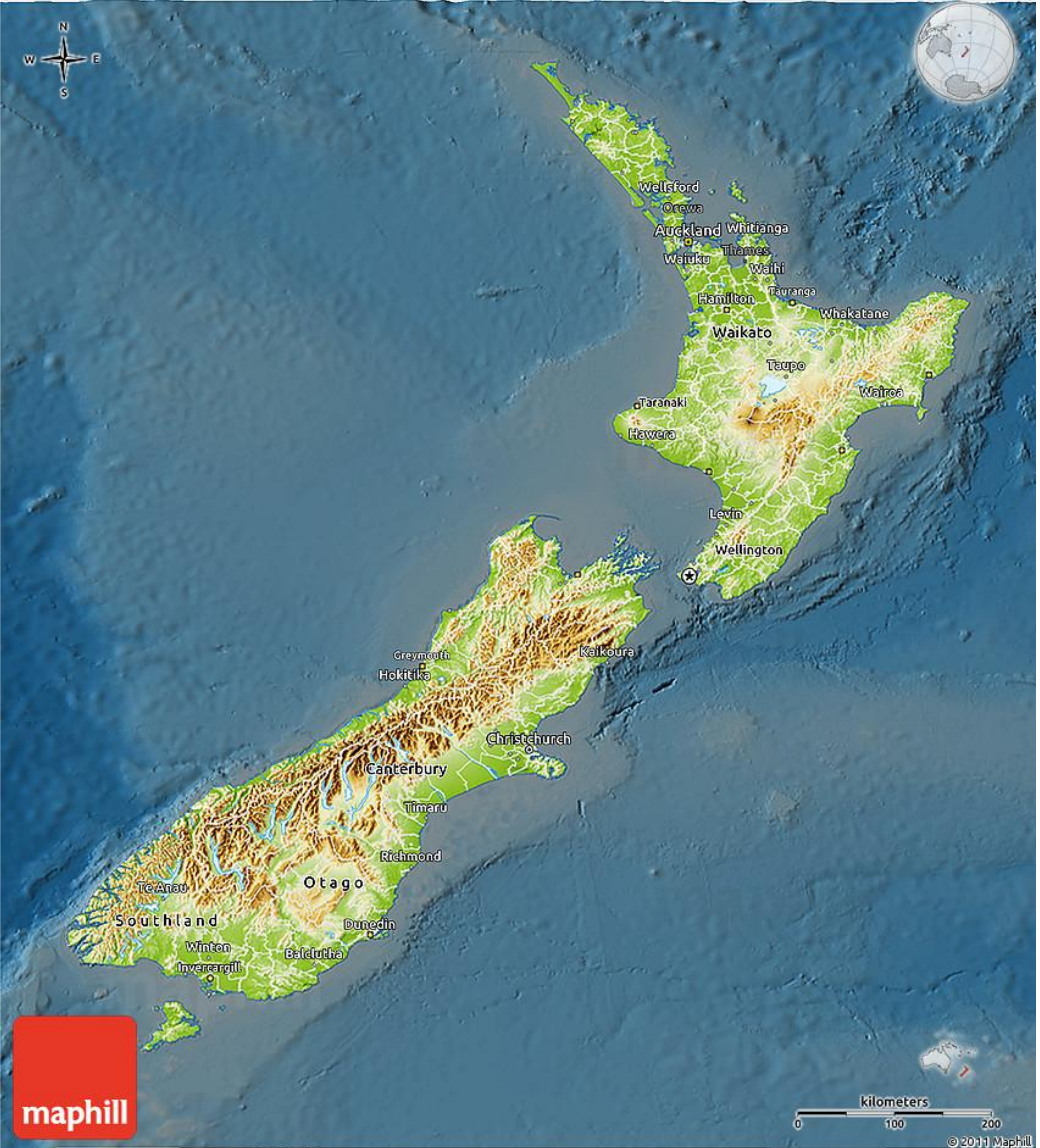
1907- Dominion of New Zealand and later member of British Commonwealth of Nations

Present- Queen Elizabeth II is the head of state and is represented in NZ by a Governor-General

- Labour (liberal)-NZ First coalition with Green party support won the October 2017 election and leads the central government at this time.

- Jacinda Ardern is current Prime Minister.

Geography and Climate



Area – 268,000 km^2 (MN ~225,000 km^2)

Coastline – 15,000 km

Population – 4.8 million (MN ~5.5 million)

Climate – Maritime

Wet on West side (~2->10 meters)

Dry on the East (~0.5-1 meter)

Topography –

2/3rd “relatively steep hill or mountainous” terrain and has a slope >30^o

1/3rd “flat to rolling country” with slopes <= 16^o

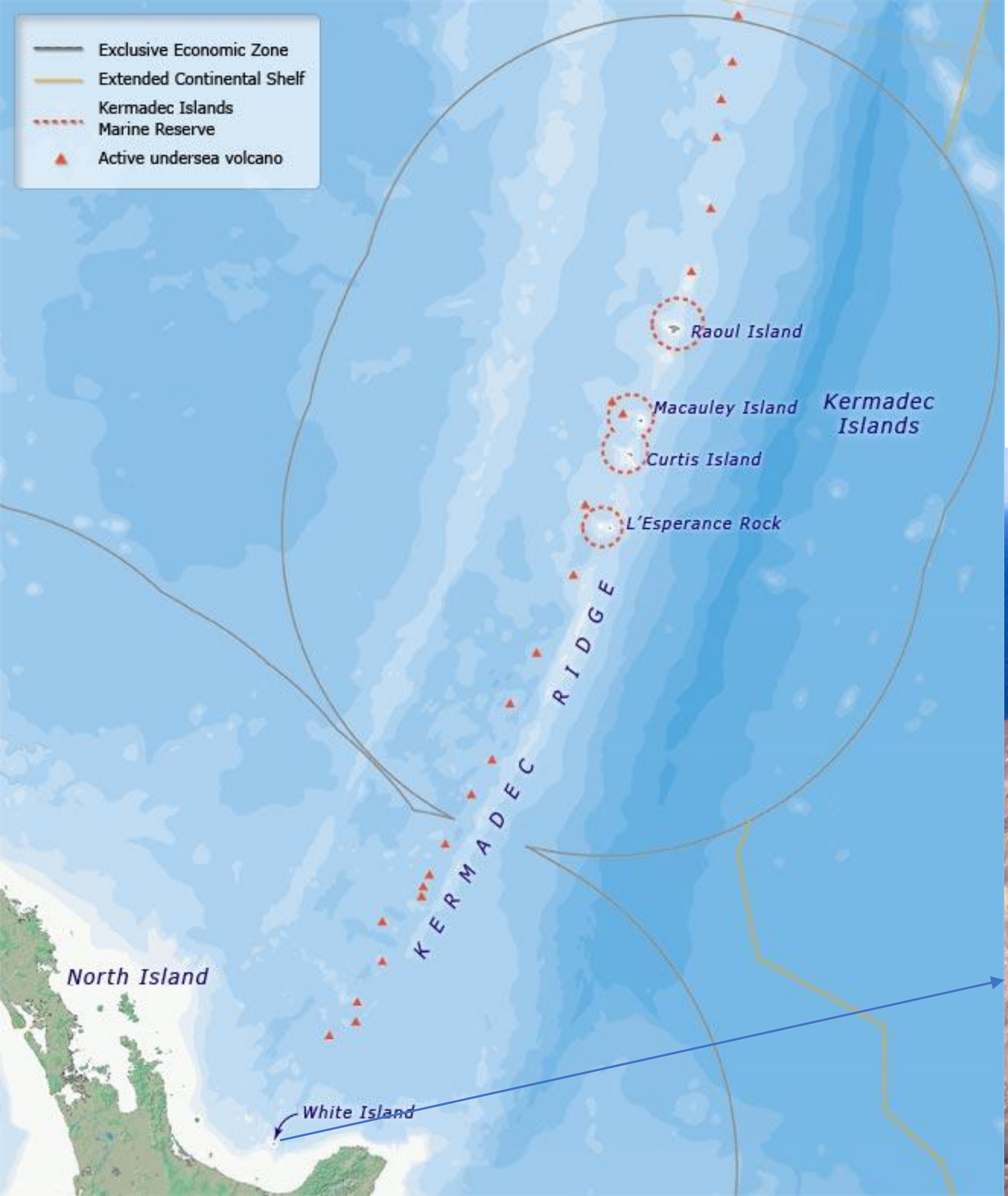
Other Islands – Chatham Islands (650 km SE), Kermadec Islands (800-1000 km NE), and Stewart Island (30 km S)

Geology and Landforms

- Located on a plate boundary
- Actively volcanic from central North Island to Kermadec Islands
- Southern Alps on South Island
- Glaciers
- Karst

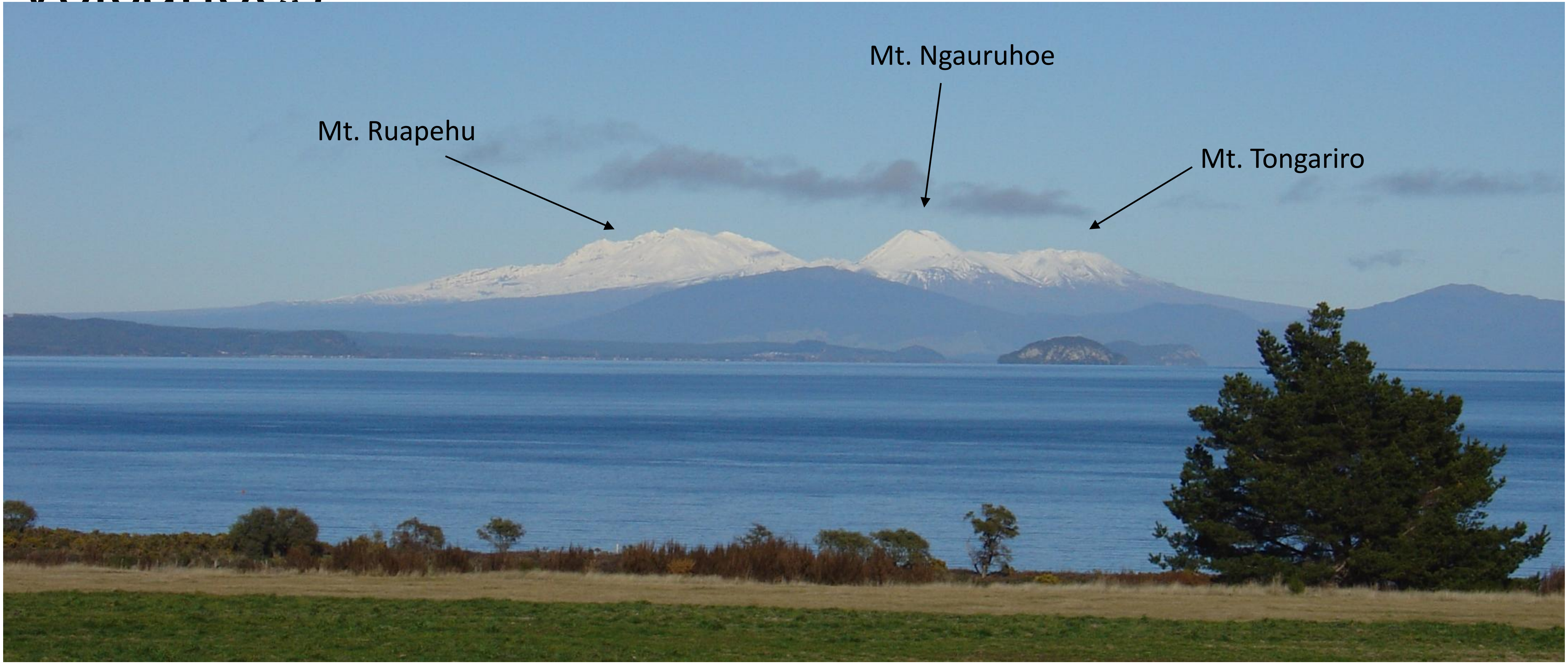
[GNS Science- The Geology of New Zealand]

Kermadec Islands



White Island crater lake

Central North Island Volcanoes



Geothermal Activity

Champagne Pool

Lady Knox Geyser erupting

Southern Alps and Glaciers

Franz Josef Glacier

Canterbury Plains

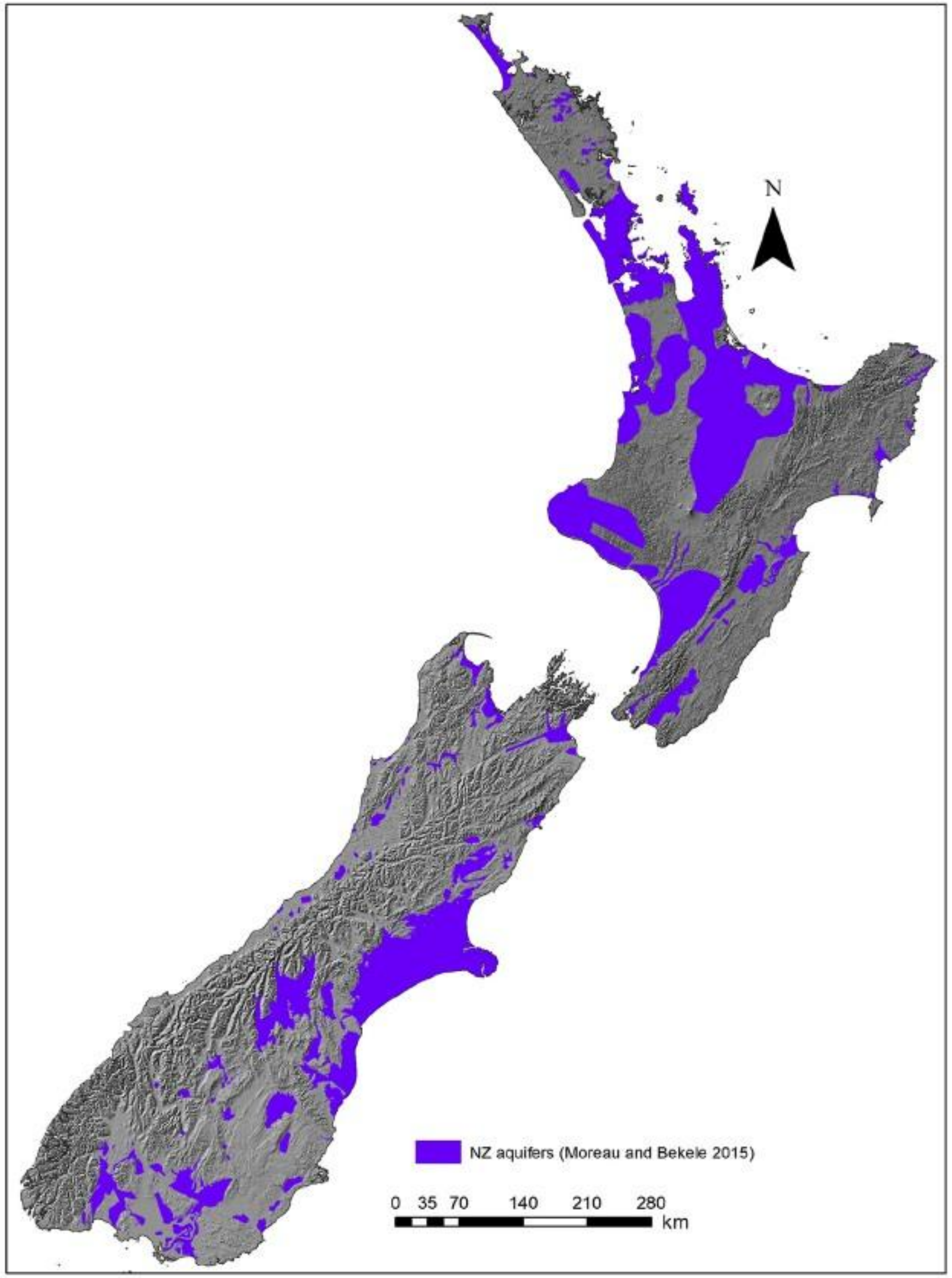


Figure 5. Location of aquifers zones across New Zealand. Modified after Moreau and Bekele (2015) and Tschritter et al. (2017).

Hydrogeology

- Geologically young sediments and volcanic deposits
- Limited aquifer hydraulic properties
- High recharge values in porous soils of volcanic origin
  - e.g., recharge ratios on the order of 50%.
- 200 identified aquifers in New Zealand
  - 60% are <100 km^2 while only 12% are >1,000 km^2 in areal extent
  - Largest aquifer is about 5,330 km^2
  - Combined total size of all identified aquifers is ~70,500 km^2, or about 26% of the total land area
- Small aquifers compared to US
  - Ogallala Aquifer covers 451,000 km^2

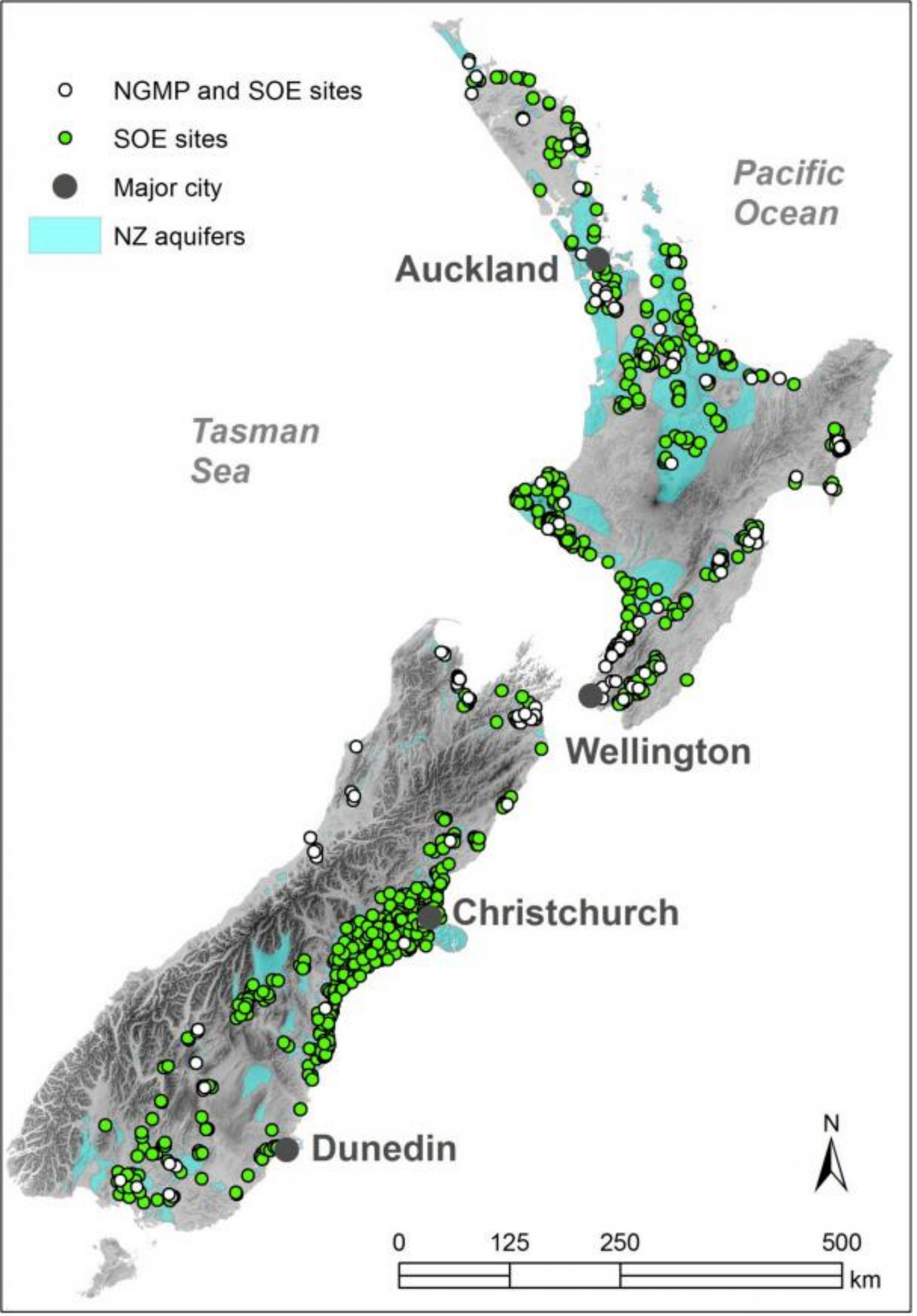


Figure 4: Location of SOE and NGMP sites and main aquifers in New Zealand. Aquifer shapefiles were sourced from Moreau and Bekele (2015).

Groundwater Monitoring

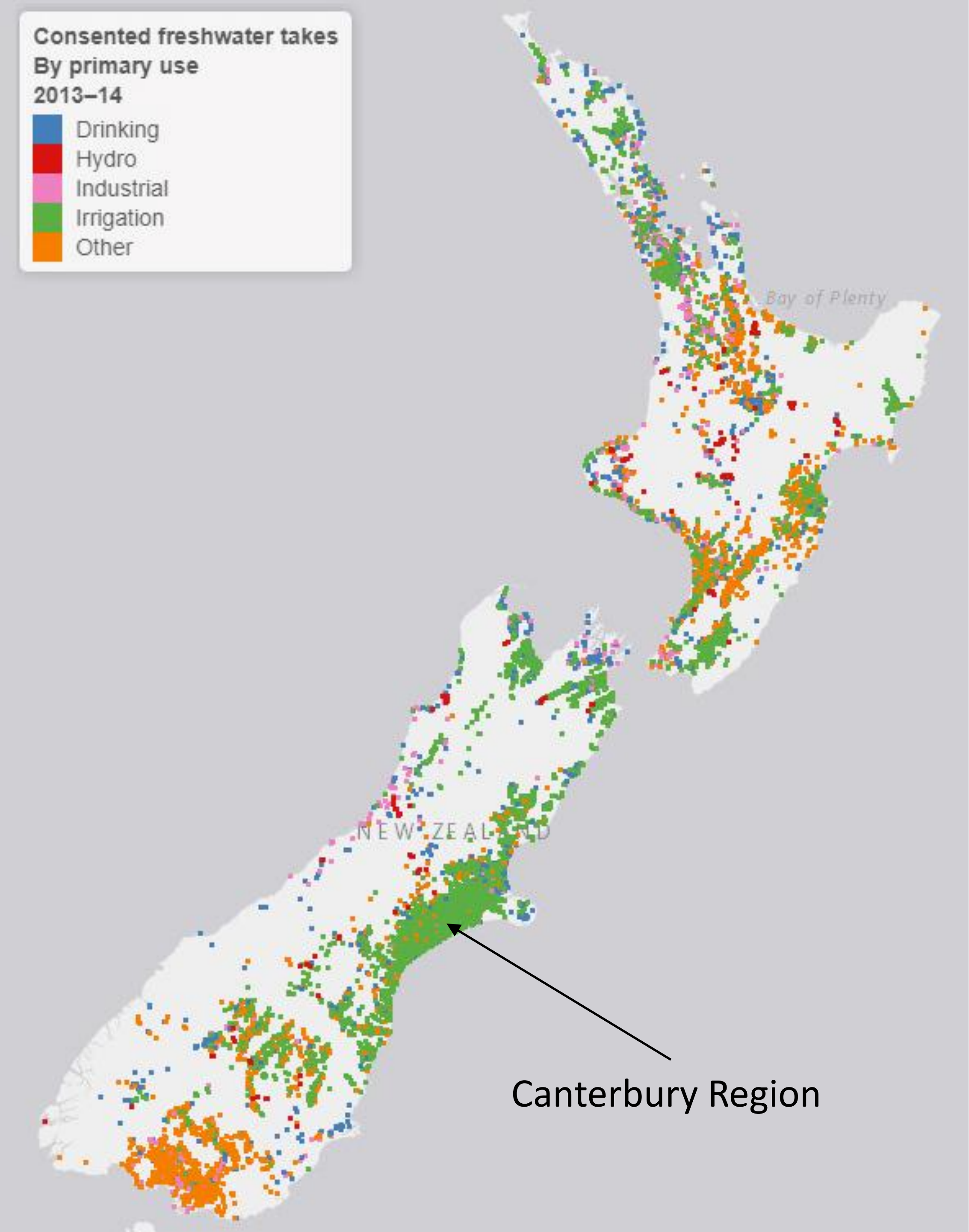
National Groundwater Monitoring Program (NGMP)- GNS Science

- Established in 1990
- ~116 sites (white dots)

State of the Environment (SOE)- Regional Councils

- ~853 sites (green dots)

- 6 springs
- Few dedicated monitoring wells
- Mostly unconfined aquifer wells
- Median well depth 75 feet (23 meters)
- Deepest well 1640 feet (500 meters)
- Quarterly sampling for 17 water quality variables

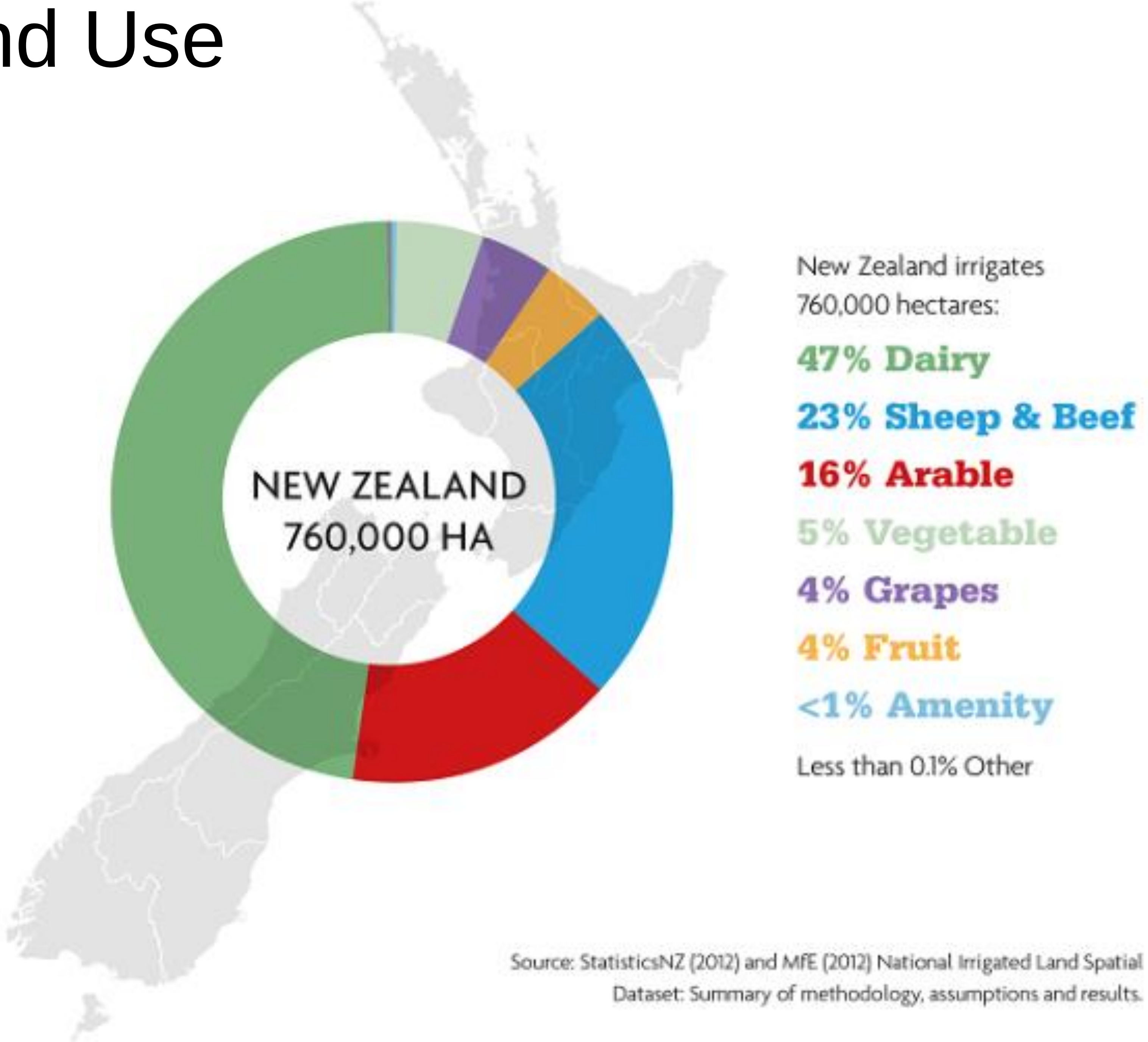


Freshwater Use

- 'First in, First served' water allocation
- Resource consents required to take water
- 51% used for irrigation in July 2013 to June 2014 (excluding hydro-power)
- ~2/3^{rds} of consents are groundwater
- Groundwater constitutes only 30% of the total annual volume of freshwater taken for consumptive use

Irrigated Land Use

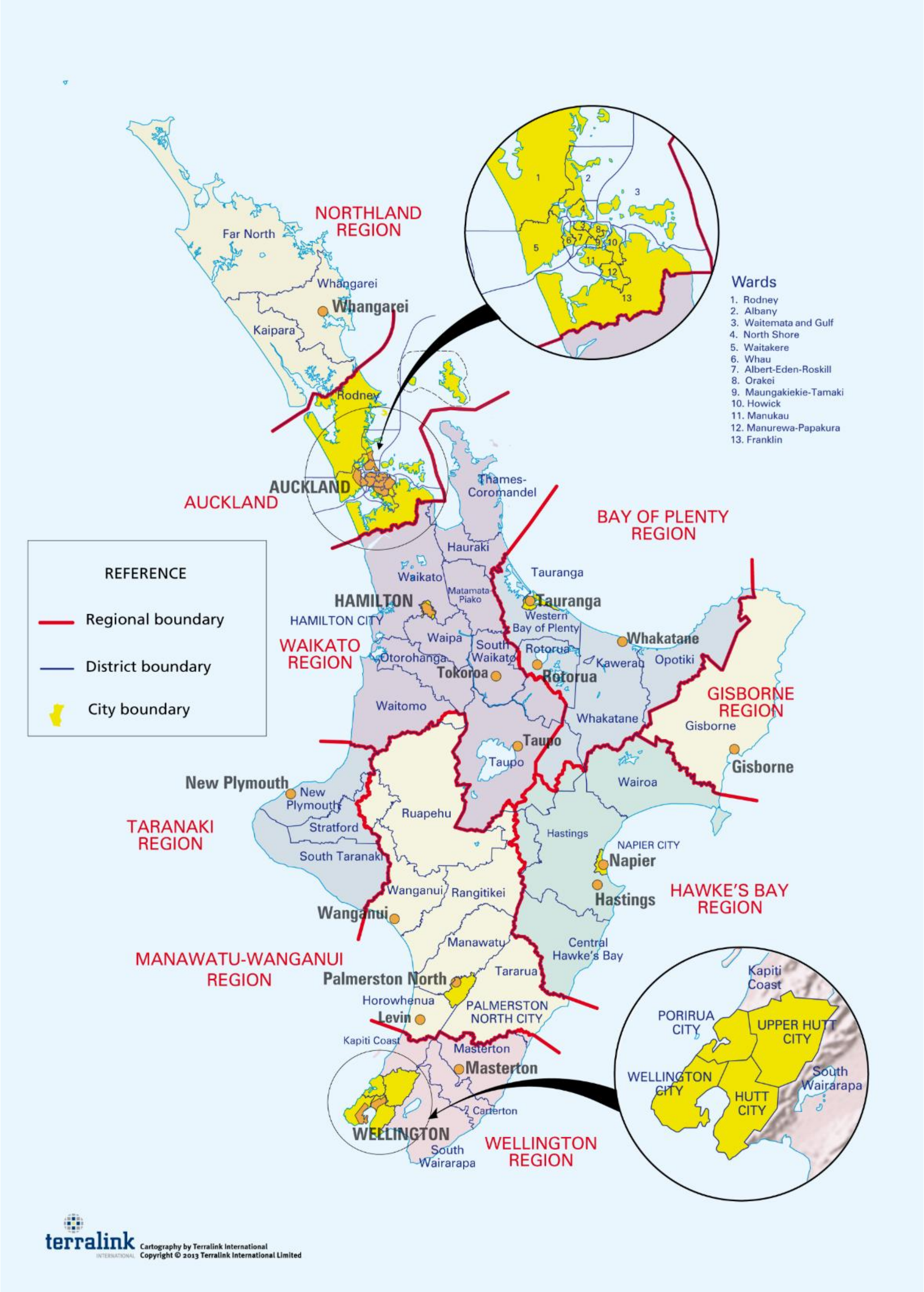
1 hectare =
~2.5 acres



IrrigationNZ

Early history of water management in NZ

- The first NZ law regarding management of fresh water (FW) was passed in 1941.
- It did not specifically address GW. The objective of law was erosion and flood control. However, it established local level **Catchment Boards** which ultimately became the 16 **Regional Council**s that make up the first tier of local government in NZ today. Regional Council boundaries are shown in the following slide.
- After review in the 1960s, this law was replaced by a new one. The focus of the new law was still surface waters and local level implementation. However, the Catchment Boards were renamed **Regional Water Boards** (RWBs).
- This new law explicitly considered GW. But regulation of GW was severely hampered by lack of information. Notably, it now required a permit to take GW.


NORTHLAND REGION
Far North
Whangarei
Kaipara
Rodney
AUCKLAND
AUCKLAND
Wards
1. Rodney
2. Albany
3. Waitemata and Gulf
4. North Shore
5. Waitakere
6. Whau
7. Albert-Eden-Roskill
8. Orakei
9. Maungakiekie-Tamaki
10. Howick
11. Manukau
12. Manurewa-Papakura
13. Franklin
REFERENCE
Regional boundary
District boundary
City boundary
Thames-Coromandel
Hauraki
BAY OF PLENTY REGION
Tauranga
Waikato
HAMILTON
HAMILTON CITY
Matamata-Piako
Western Bay of Plenty
Whakatane
Waipa
South Waikato
Rotorua
Kawerau
Opotiki
WAIKATO REGION
Otorohanga
Tokoroa
Waitomo
Whakatane
GISBORNE REGION
Gisborne
Taupo
New Plymouth
Wairoa
TARANAKI REGION
Stratford
Ruapehu
South Taranaki
Hastings
NAPIER CITY
Napier
Wanganui
Rangitikei
HAWKE'S BAY REGION
Manawatu
Central Hawke's Bay
MANAWATU-WANGANUI REGION
Tararua
Palmerston North
Horowhenua
PALMERSTON NORTH CITY
Levin
Kapiti Coast
Masterton
Carterton
WELLINGTON
South Wairarapa
WELLINGTON REGION
PORIRUA CITY
UPPER HUTT CITY
WELLINGTON CITY
HUTT CITY
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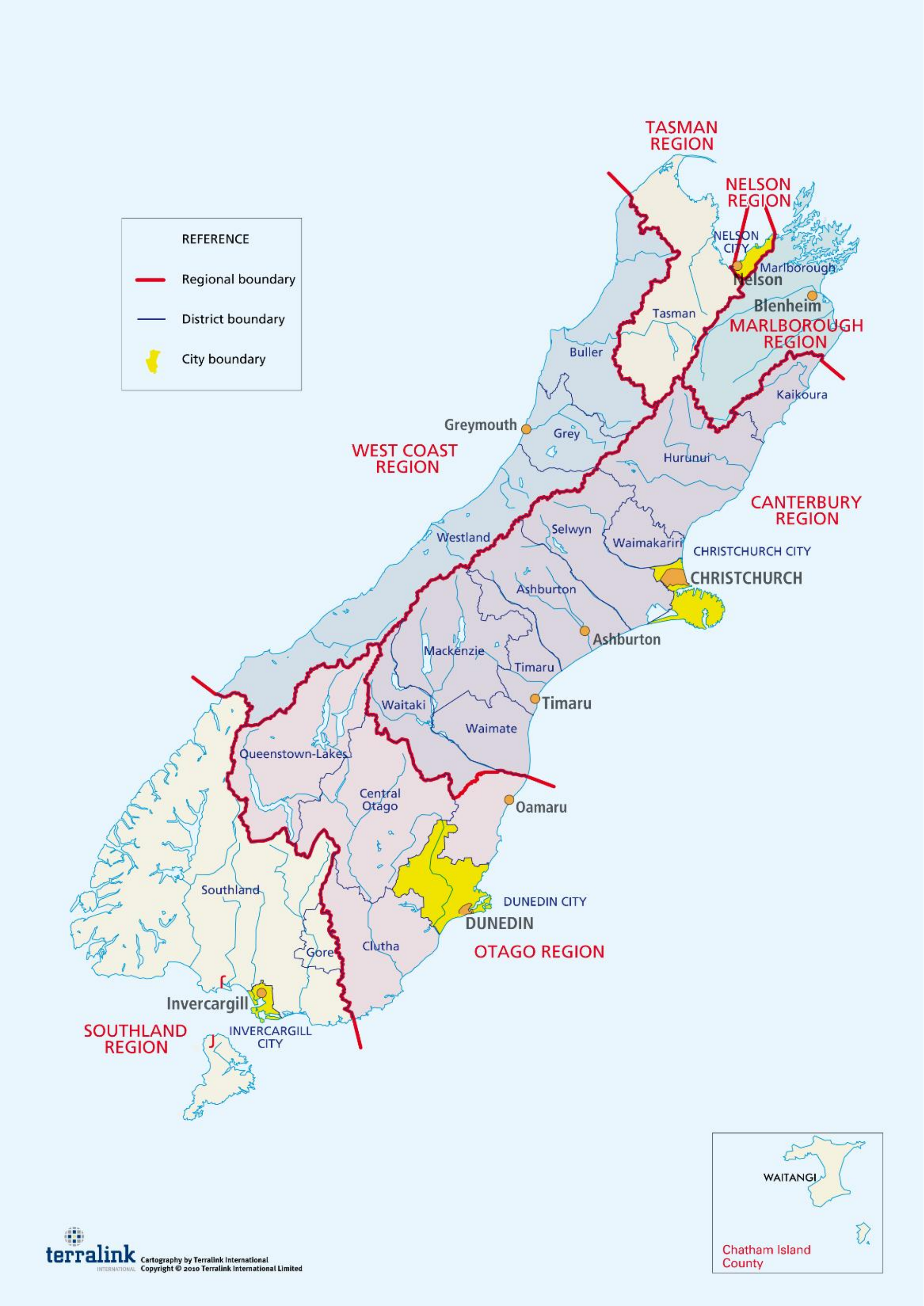
TASMAN REGION
NELSON REGION
NELSON CITY
Nelson
Marlborough
REFERENCE
Regional boundary
District boundary
City boundary
Tasman
Blenheim
MARLBOROUGH REGION
Buller
Kaikoura
Greymouth
Grey
WEST COAST REGION
Hurunui
CANTERBURY REGION
Selwyn
Westland
Waimakariri
CHRISTCHURCH CITY
CHRISTCHURCH
Ashburton
Ashburton
Mackenzie
Timaru
Waitaki
Timaru
Waimate
Queenstown-Lakes
Central Otago
Oamaru
Southland
DUNEDIN CITY
DUNEDIN
OTAGO REGION
Gore
Clutha
Invercargill
SOUTHLAND REGION
INVERCARGILL CITY
WAITANGI
Chatham Island County
terralink
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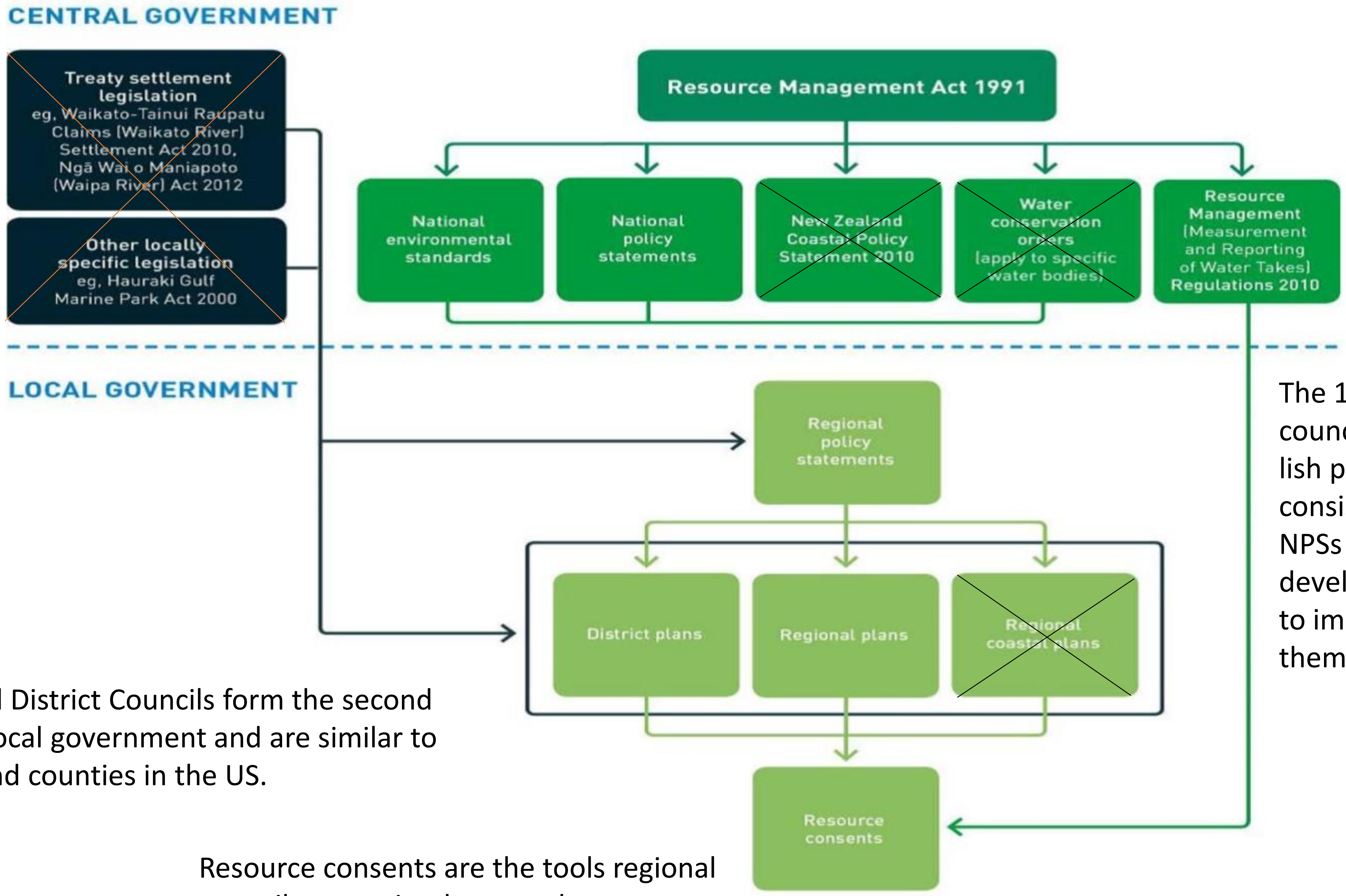
- The status of GW regulation was reviewed in 1981. Recommendations from this review included:
  - **Increased central government Science Centre and RWB staffing, equipment, and funding.**
  - Training RWB staff in **fundamental** GW science.
  - **Having RWBs require permits for drilling wells.** This was intended to provide more geologic and hydraulic data for management.*

***In 2015 some regional councils still did not require that drilling logs actually be submitted.**

Resource Management Act 1991 (RMA)

- A “Wholesale (review)… of NZ’s environmental laws occurred” in the 1980s.”
- This culminated with enactment of the Resource Management Act 1991 (RMA) which “**endeavored to incorporate into one statute the law relating to the use of land, air, and water**.”
- “The central principle of the RMA is the concept of “**sustainable management**.”
- The clear focus of the RMA with regard to water was again surface waters. Although GW is regulated under the RMA, the word GW does not appear in that Act and GW is only included within broad definitions of water.
- The RMA also recognizes the special relationship of Maori to FW.



The 16 regional councils establish policy consistent with NPSs and develop plans to implement them.

City and District Councils form the second tier of local government and are similar to cities and counties in the US.

Resource consents are the tools regional councils use to implement plans.

Provisions of the RMA relevant to GW:

- Resource consent is needed to take and use water and to discharge contaminants into water or **on or into land** that may enter water…
  - **Except** in the case of uses for: (1) **Reasonable domestic needs**; (2) **Stock watering; and (3) Firefighting;** or
  - For either uses or discharges, where allowed by **a national environmental standard** or **rule in a regional plan**.
- **An application for a resource consent must include an assessment of "adverse environmental effects**" (AEE).
- Public notification of an application for a resource consent is **discretionary,** but must be given if AEEs are likely.
- The duration of a resource consent is specified in the consent, but cannot exceed 35 years and defaults to 5 years if not otherwise specified. For flexibility, some regional councils now limited consent durations to allow for uncertainty from climate change.

Central government

- The RMA established the Ministry for the Environment (MfE), which provides advice on policies and issues affecting the environment.
- The Environment Minister has substantial discretionary authority to:
  (1) **Recommend national environmental standards (NES) and policy statements (NPS).** But, **only** one NES (DW) and one NPS (NPSFWM) have been adopted by central government in the nearly 30 year history of the RMA. The NPSFWM has been **amended** twice and is in a state of **flux** today.
  (2) Deciding whether or not to convene a Board of Inquiry (BOI) in matters of national significance.
  (3) Monitor the effect and implementation of the RMA; and
  (4) Monitor the relationship between central and local governments.
- BOIs essentially allow discretion for central government to override regional councils. Persons appointed to a BOI are supposed to have expertise in the matter under consideration. BOI decisions can only be appealed on a question of law.

RMA reform

- The following shortcomings of the RMA were highlighted in various assessments within 10 years of its adoption:
  1. Many provisions were “Over(ly)-bureaucratic”;
  2. “Inadequate attention (was) given to” environmental monitoring”;
  3. There had been a “Lack of national leadership” (e.g., NES and NPS); and
  4. Public participation provisions were “Illusory” in nature due to:
     1. The “adversarial nature” of council proceedings;
     2. “Unfriendly attitudes” of councils and staffs toward the public; and
     3. Government bias toward resource development.
- Additionally, historic NZ advantages that facilitated water quality protection were undergoing change.

Historic NZ advantages WRT FW Quality

- Management of FW in NZ has traditionally benefitted from:
  1. Relatively **abundant water resources** due to its maritime climate (e.g., a national annual mean precipitation of 2.1 m with over 10 m in mountainous areas of the southwest S Island compared to 0.77 m for the US as a whole;
  2. Relatively **low population density** (15 persons/km^2 compared to 33 for the US as a whole.
  3. **Lack of major manufacturing** industries; and
  4. **Dispersed, low density agricultural production** (e.g., range-fed beef and sheep, forestry, and relatively small family farms).

- Factors that have changed this situation include:
  1. **Dairy intensification (by inserted a high density major industry with high pollution potential)**;
  2. **Lack of central government guidance** (already noted above); and
  3. **Projected impact of climate change** on FW in critical regions (notably, **ECan, Waikato, and Hawkes Bay**).

Dairy intensification

- NZ exports 95% of its dairy production, placing **NZ first in the world in terms of global dairy exports** (accounting for 29% worldwide). China is the primary customer. The 28 countries of the EU are in a close 2nd place.
- Dairy intensification in NZ has resulted in: (1) **consolidation and major expansion** of the industry (increasing average herd size from ~60 cows in 1975 to >400 now. **Dairy cow numbers in NZ haveroughly doubled since 1990 and the value of NZ dairy exports increased from NZ$2 to NZ$15.5 billion between 1990 and 2014**.
- The result has been a major increase in concentrated solid and liquid animal wastes and other impacts from the increase in pastures.

The Basic Problem of Dairy Intensification

(some people actually study this stuff…)

Average dairy cow: (1) 2.1 L/urination event; (2) ~ 7 events/day; and (3) NH_3-N of ~15 g/L (Misselbrook et al.-2016).

~220 g NH_3-N/cow/day (88,000 g/day or 94 #/day for a herd of 400 cows

One proposed development in Canterbury for a herd of 80,000 ~ waste load of a city of 400,000

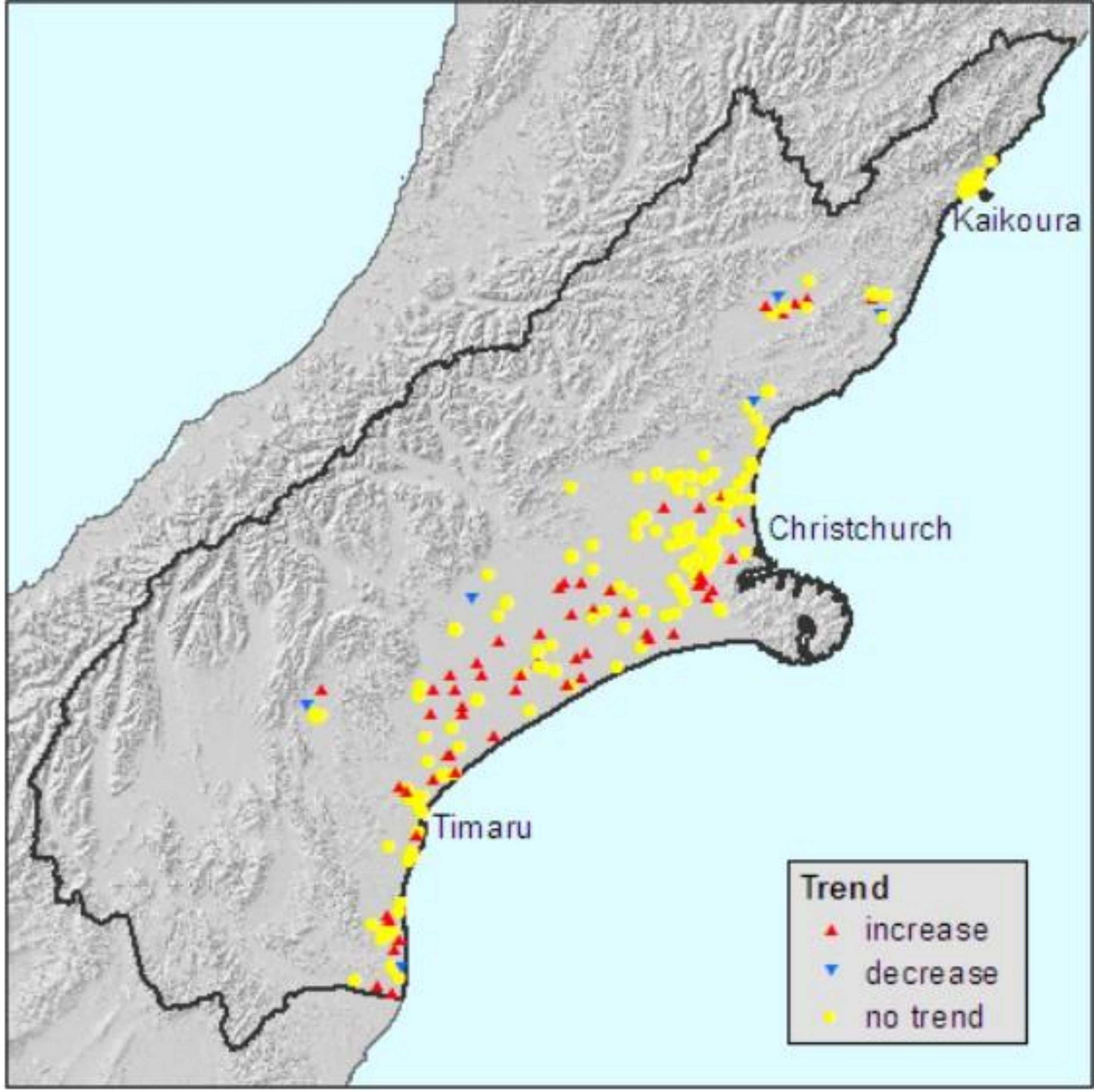
Dairy intensification impacts on WQ

1. Tens of thousands of hectares of forest in the Waikato region were converted to dairy pasture between 2000 and 2010 (see next slide);
2. This was accompanied by large increases in fertilizer use (e.g., N fertilizer use increased by >800% and PO_4 fertilizer use increased 100% between 1990 and 2005);
3. Pastoral farming now occupies 40% of NZ’s land area;
4. Dairy intensification is occurring on relatively flat and highly fertilized pastures along streams and in areas of GW recharge.
5. Water quality has declined in major dairy farming areas due to increased sedimentation and nutrient loading, now recognized as a major national problem.

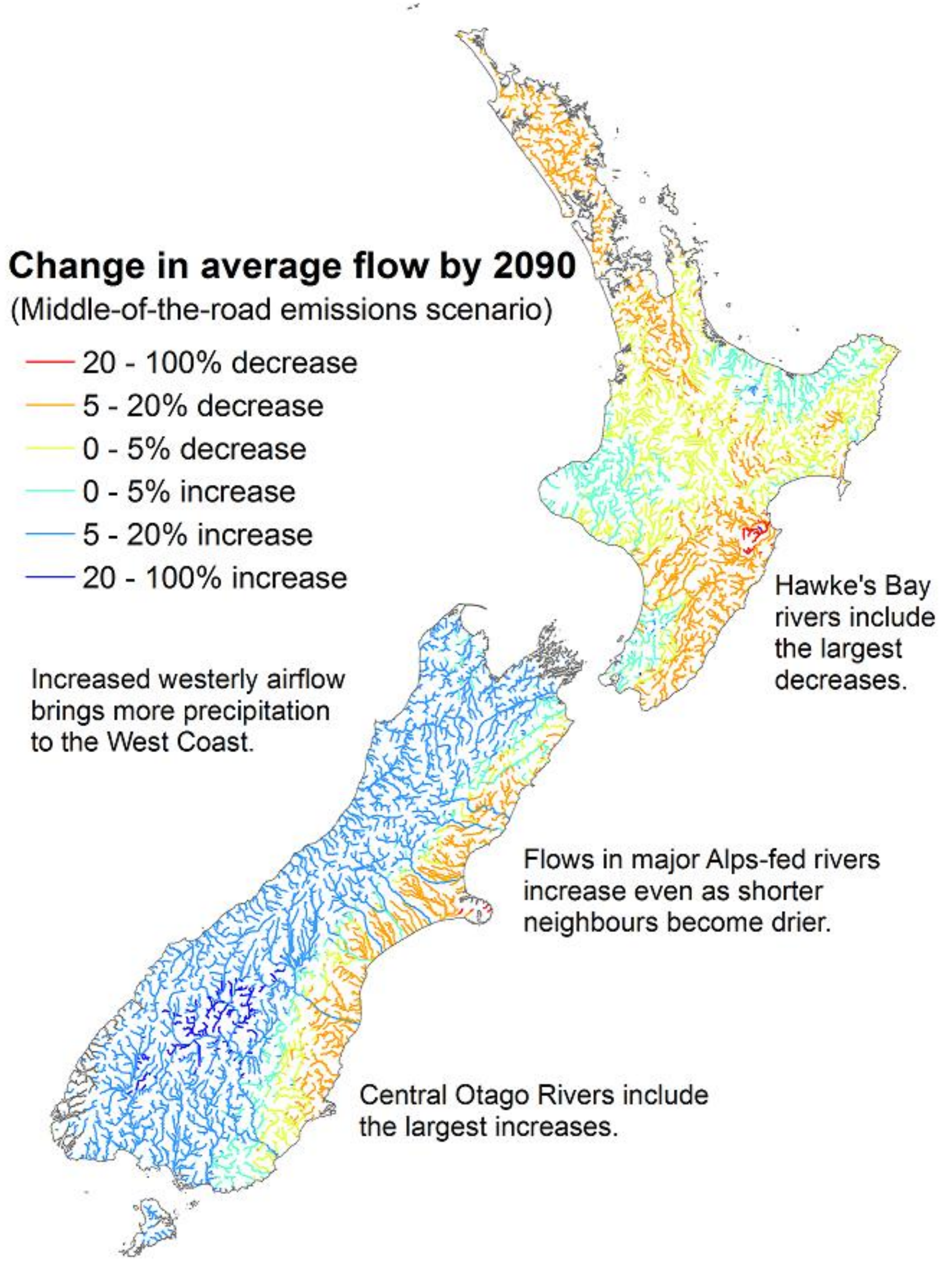
Here's what it looks like (the Waikato River, NZ's longest, is to the left).

Forestry to dairy conversion in the Upper Waikato catchment. The actual increase in dairying land in Waikato by 2012 had already exceeded what the modelling predicted for 2020.

Here's what it's done to GW in the ECan region (red triangles indicate increasing trend in NO_3-N over 2003-2012). Highest levels approach 40 mg/L.



Trends in nitrate concentrations in Canterbury groundwater, 2003 to 2012 (C. Hanson).



Projected climate change impacts most likely to impact FW:

1. Changes in precipitation patterns resulting in reduced FW quantities on the E side of NZ.
2. Increasing incidence of extreme weather events (e.g., high temperatures, droughts, more winds, and major storm events).

GNS performed one study of the potential impact of climate change on GW in NZ in 2010.

RMA reform initiatives

1. Increasingly evident shortcomings of the RMA, particularly the inability to resolve "**the tension between environmental protection and economic development**" from dairy intensification, led to growing political pressure for reform of FW management over the last 10 years.
2. In 2008 the Labour government released a **draft of its NPSFWM (**the **first NPS** under the RMA) and **appointed a BOI** to consider it. Shortly thereafter Labour lost and National won the central government election.
3. Nov 2010: New national regulations that had been underway were adopted mandating **measurement and reporting** of all **active water takes of 5 L/sec or greater** (79 gpm).

4. May 2011: The National government **released its NPSFWM**. As released, it **weakened** what Labour had proposed.
5. 2014 and 2017: The National government amended the NPSFWM and passed new RMA amendments. These included restrictions on public participation and establishment of a new national target to make 90% of NZ rivers and lakes swimmable by 2040.
6. Sep 2015: An Environmental Reporting Act came into effect requiring MfE and Statistics NZ to regularly report on the pressures, state, and impacts relating to fresh water.

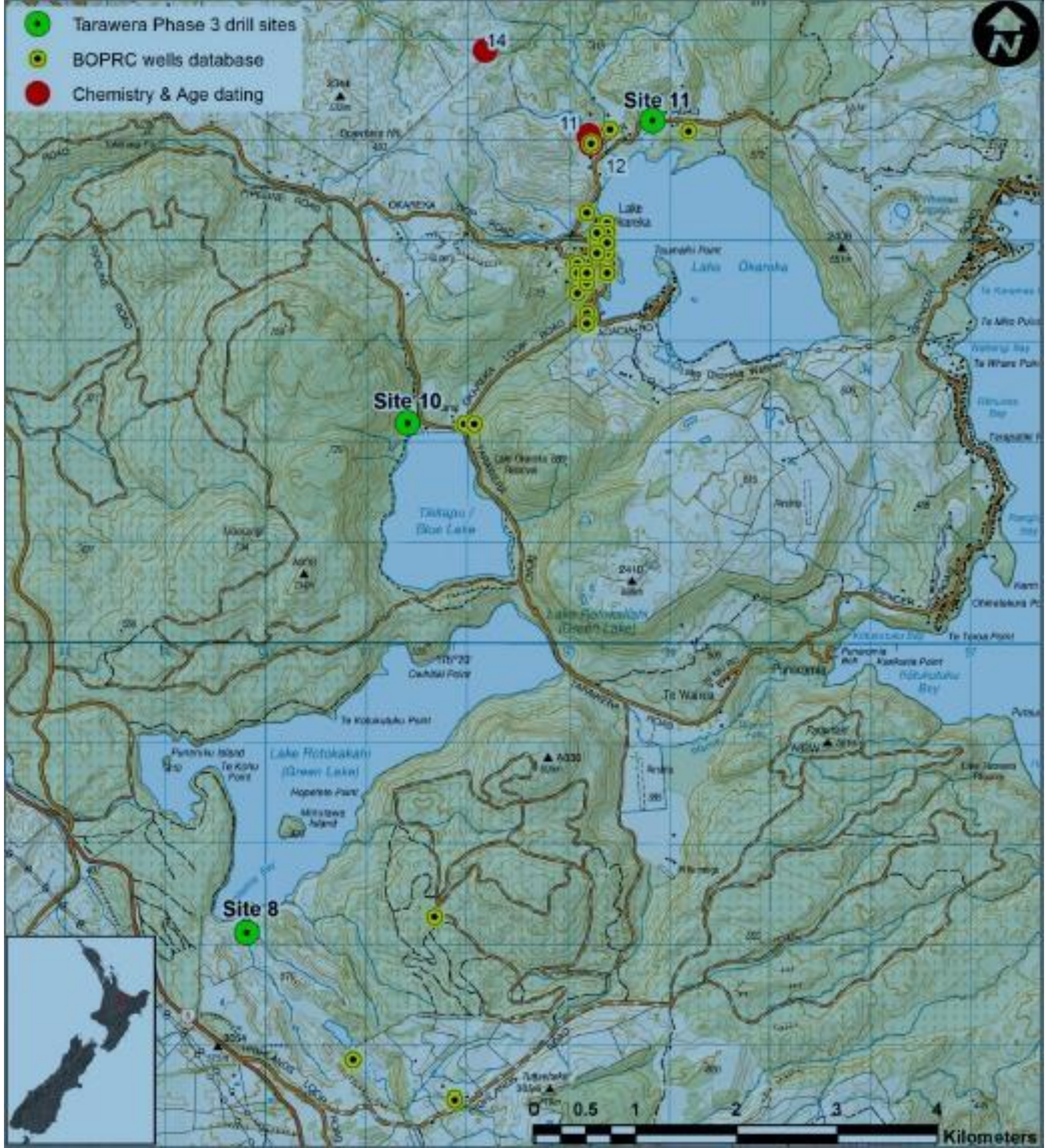
2017-2018: Labour government FW initiative

- Labour won the Oct 2017 election and the new government called for a "**fundamental review**" of resource management. Labour intends to repeal the most **"misguided"** changes to the RMA made by National in 2017.
- Labour considers WQ a major issue it wants to confront. Its "overall" objective, "is (to) **get back to the clean rivers that we used to have** a couple of decades ago."
- **Labour intends to amend the RMA within one year** with a new NPSFWM, new national standards, and new rules to stop degradation of FW quality.

Technical Example: GW modeling

- There are a wide range of competencies with regard to GW modeling in NZ (some good, some not so good). Adverse factors are:
  - Lack of tertiary hydrogeology education in NZ and uneven competency of imported personnel hired from other countries.
  - No widely accepted standard procedures.
  - No professional codes (government regulatory or from professional organizations).
  - Sparse data requires greater judgement and use of assumptions (e.g., most pump tests in NZ are single well tests without observation wells so S is not known from data and there may be only a few wells in a large area, see next slide).

Sparse data:

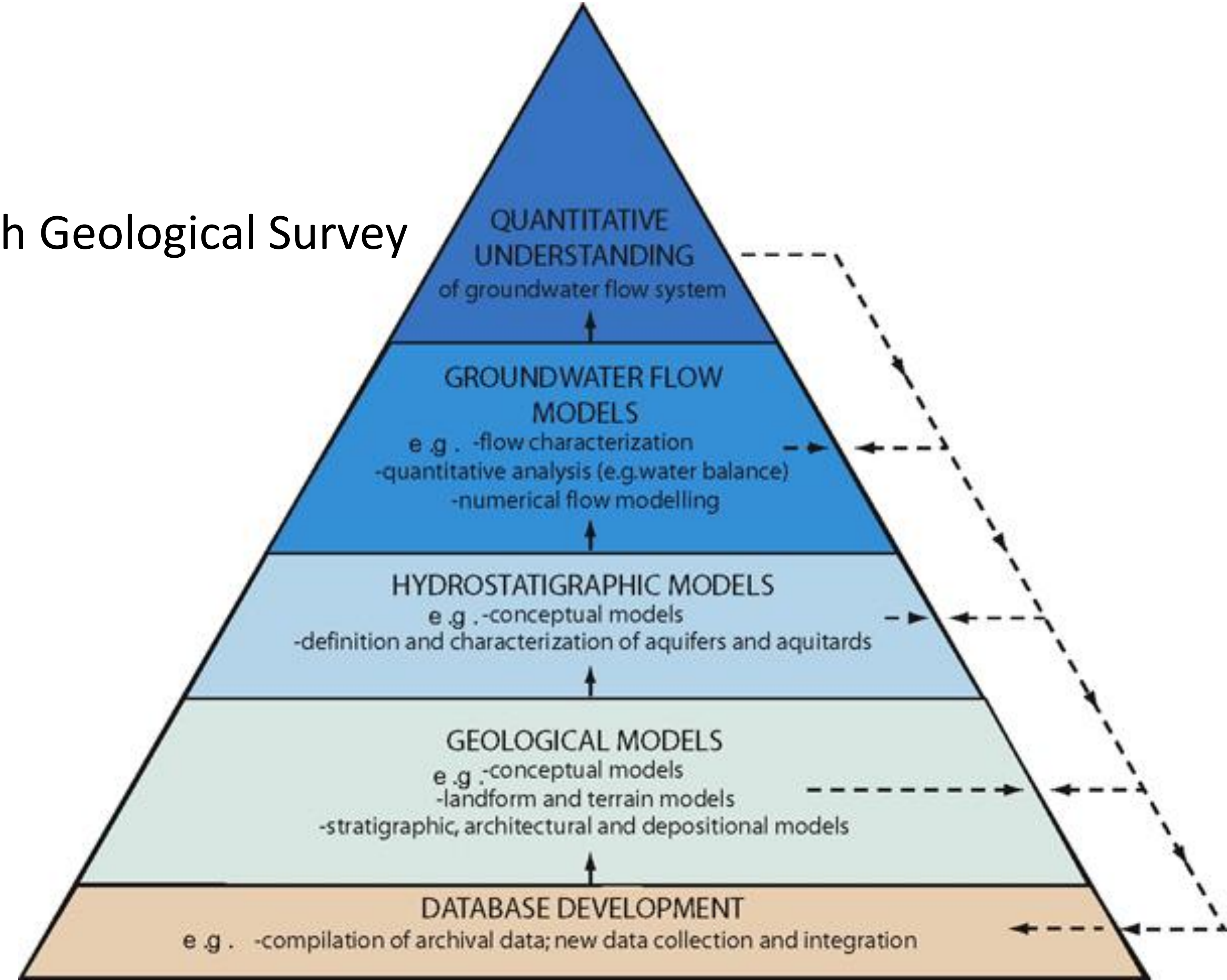

Tarawera Phase 3 drill sites
BOPRC wells database
Chemistry & Age dating
Site 11
11
12
14
Site 10
Site 8
Lake Okareka
Lake Rotokakahi (Green Lake)
Tikitapu / Blue Lake
0 0.5 1 2 3 4
Kilometers
N

Focussing on the case of a GW model prepared by the Hawkes Bay Regional Council (HBRC) for the Ruataniwha Plains

Ruatanwha Water Supply Scheme (RWSS) Early Timeline

1. As both regulator and developer, HBRC had an obvious conflict of interest.
2. Sep 2007 – GNS Science offered to assist the Hawkes Bay Regional Council (HBRC) GW modeler in constructing a geologic model. The offer was rejected as he felt a geologic model wasn't important (see next slide).
3. 2008 - ~7,000 hectares were already under irrigation, mainly using GW. HBRC began planning for a dam to supply water to irrigate an additional 25,000 hectares, primarily for dairy farms.
4. Mar 2009 – HBRC completed development of a steady-state GW flow model implemented using Visual ModFlow (VMF).

Royse et al. (2010), British Geological Survey



5. Sep 2010 – HBRC completed development of a transient GW flow model on the VMF platform.
6. Mid-2012 – A report estimated that the RWSS would increase N and P leaching from farms to already polluted streams by 25% and 22%, respectively.
7. Jun 2012 –HBRC contracted with GNS Science to undertake various GW modeling scenarios for planning of the RWSS project using the HBRC GW flow model.
8. Oct 2012 – GNS Science notified HBRC of substantial problems with the HBRC GW flow model and recommended rebuilding it because it “was not fit for purpose”.
9. Feb 2013 – HBRC cancelled its contracts with GNS Science rather than rebuild its model.

Review of HBRC's Ruataniwha GW flow model

The GNS Science review of the HBRC GW flow model for the Ruataniwha Plains set forth a number of major concerns and recommendations. Example concerns were:

1. The HBRC model oversimplified site geology (see geologic x-sections in next 3 slides).

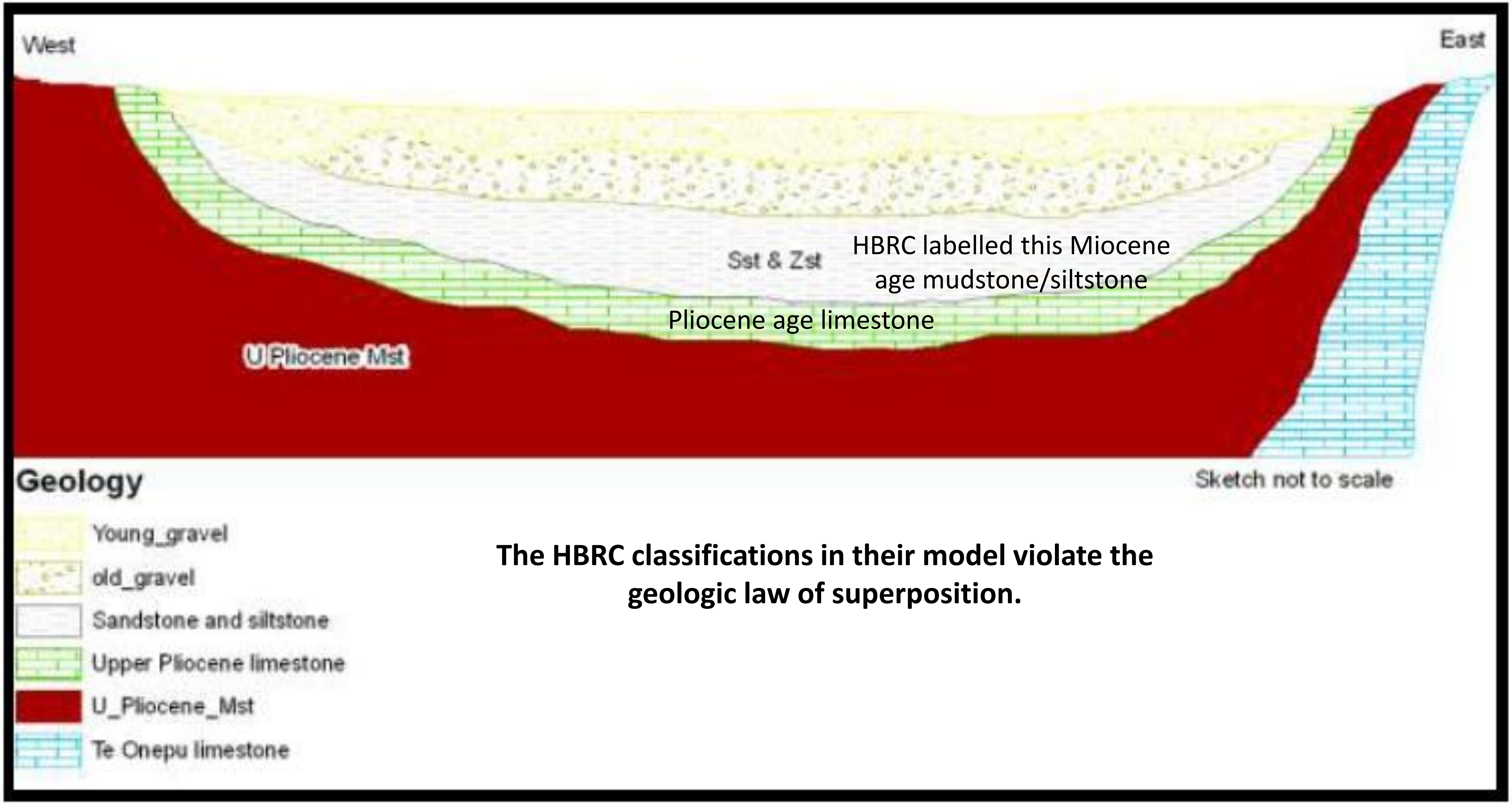


Figure 3: Typical schematic cross section of the Ruataniwha basin (West-East).

According to HBRC Model

NW, A

SE, A'

Francis (2001)

Porour & "highly per-meable" Upper Pliocene Limestones

Upper Pliocene Mudstone

HBRC GW flow model

Mid-Lower Pliocene Mudstone & Siltstone

Miocene Mudstone & Sandstone

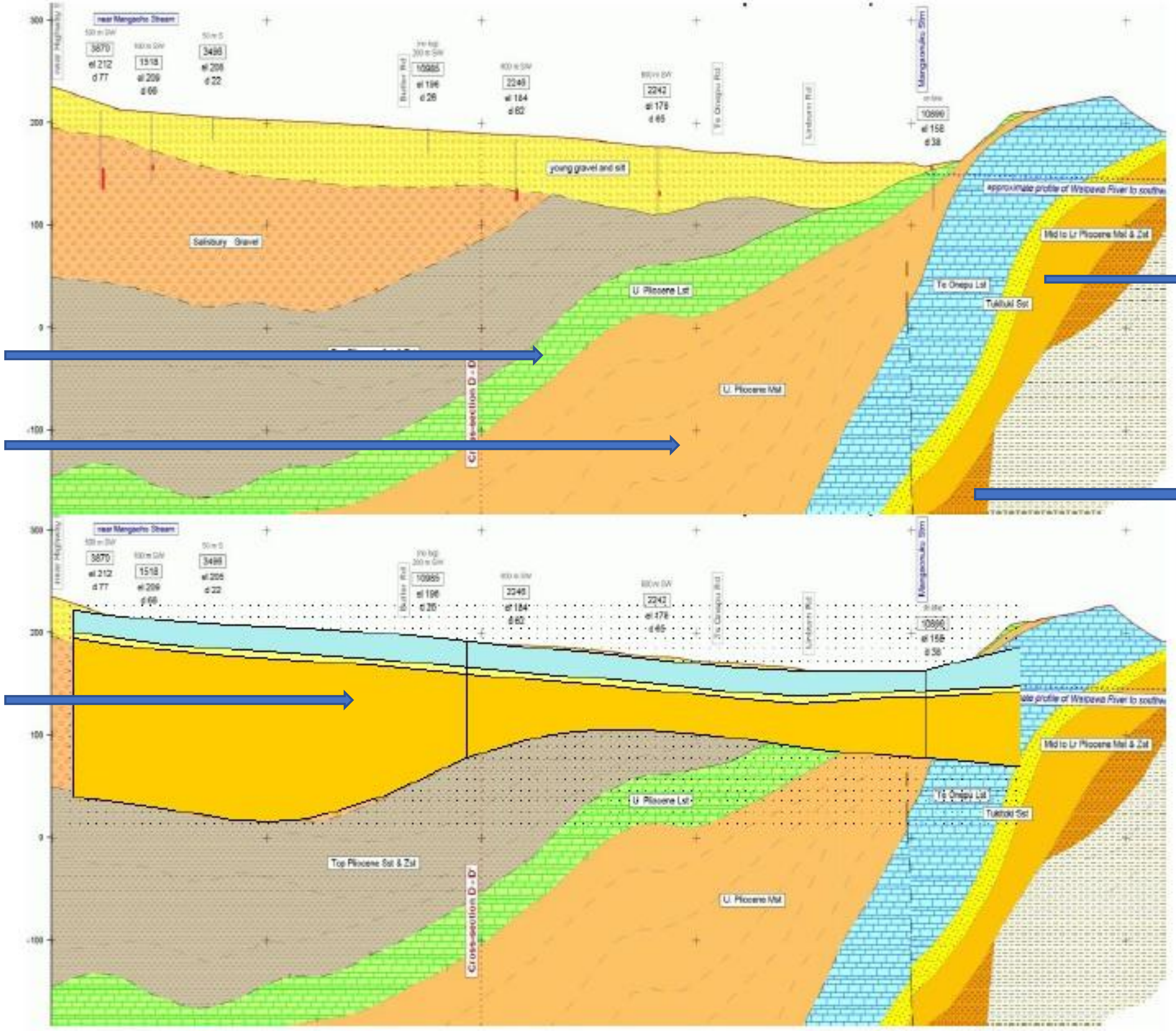
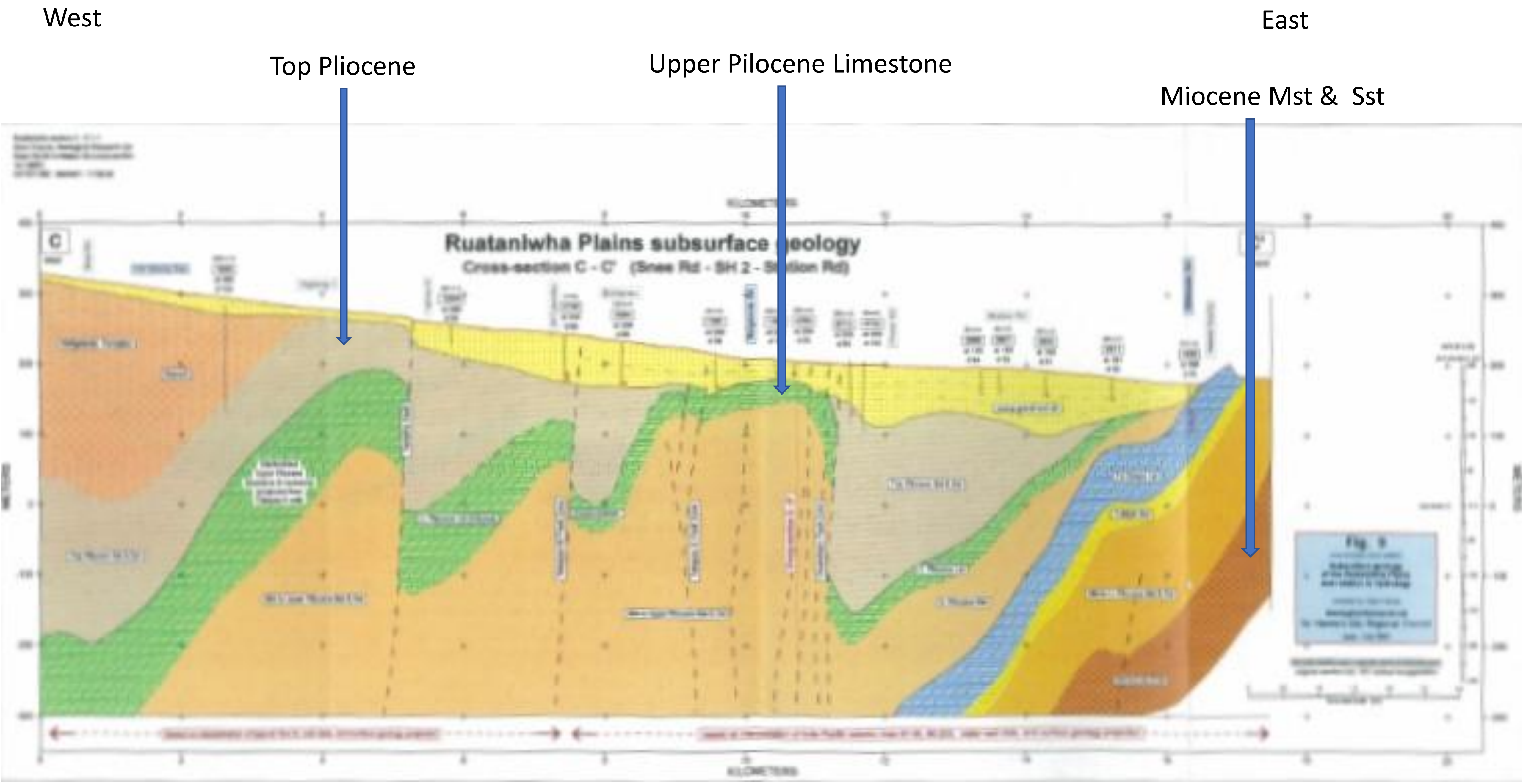


Figure 3: Cross section A–A′ (Francis, 2001), with overlay of model layers from HBRC model in the bottom figure.

From Francis (2001): Not your average homogeneous, isotropic layer cake…



2 The HBRC model assigned different locations of hydraulic conductivity (K) zones with different values for model layers in its steady state and transient models. **This essentially meant the geology of these models was different**.

3 Model K values for the confining layer were not much different than for the underlying gravel aquifer (see table in next slide).

3. The HBRC did not cross-check its K values with actual data from hydraulic tests or information on actual geology.

4. In some cases, **streams are effectively implemented in model layers 2 and 3 rather than being exclusively in the top layer** (see figure on 2nd following slide).

5. Discretization was too course. HBRC used uniform grid cell dimensions that were 500 m x 500 m. This mean that all features such as streams and wells had those dimensions instead of being refined to more a appropriate smaller size.

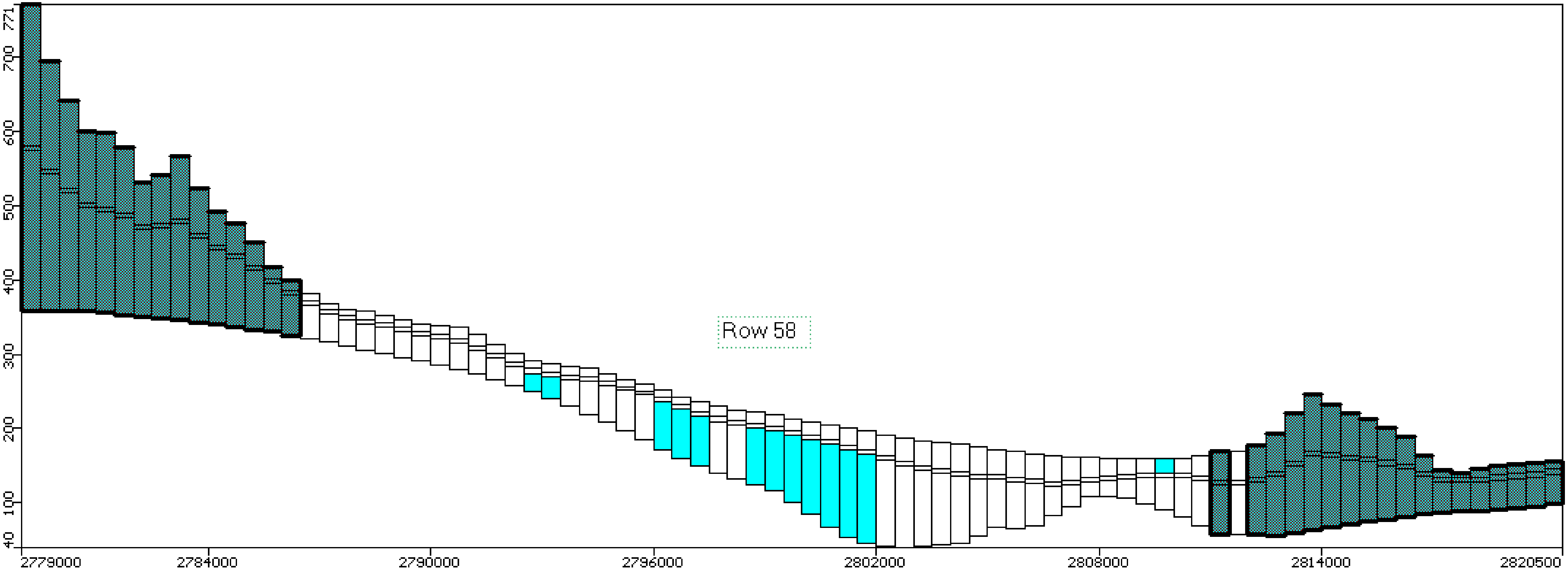
HBRC model hydraulic conductivity (cm/sec)

Steady State Model

Layer 2 - Clay		Layer 3 - Gravel	
Zone	K	Zone	K
5	0.00232	3	0.00694
10	0.0255	4	0.0116
11	0.000116	8	0.0104
13	0.00116	9	0.0521
14	0.0521	12	0.00232
15	0.00232		
Mdn	0.0023		0.0104

Transient Model

Layer 2 – Clay		Layer 3 - Gravel	
Zone	K	Zone	K
2	0.00382	2	0.00382
3	0.0694	3	0.0694
4	0.0590	6	0.00474
5	0.00116	8	0.00116
8	0.00116		
9	0.0694		
Mdn	0.0314		0.00428


771
700
600
500
400
300
200
100
40
Row 58
2779000
2784000
2790000
2796000
2802000
2808000
2814000
2820500

GNS legal counsel recommended that GNS insert this disclaimer in its contract and any reports stemming from it:

> The Client has provided the Transient model for use in the Services and the Consultant has accepted that model "as is", is not required to verify its accuracy and completeness, and **therefore (GNS) accepts no responsibility for its accuracy, completeness or fitness for any purpose including the creation of New Materials.** Accordingly, the Consultant makes no representation or warranty as to the suitability of the Materials or the New Materials for any purpose.

This obviously meant GNS had no confidence in the HBRC model.

RWSS Later Timeline

1. Jun 2013 – National, indicating its support for the RWSS, identified it as being of national significance and initiated a BOI hearing. No member of the BOI had any relevant scientific credentials.
2. Jun 2014 – After a lengthy hearing process, the BOI granted resource consent to HBRC for the RWSS, but added an unexpected dissolved inorganic nitrogen stream quality limit that would preclude the project **IF** enforced.
3. Aug 2014 – An academic paper on the economic viability of the RWSS concluded "that there is no economic or commercial rational to proceed."
4. 2016 – Total project cost was estimated at NZ$906 million.

5. Sep 2016-Jul 2017 - The Royal Forest and Bird Protection Society of NZ, Inc. (F&B), filed a lawsuit in the High Court over the legality of a government land swap needed for the dam to proceed. They lost in the High Court, won in the Court of Appeals, and finally won in the NZ Supreme Court.
6. Jul 2017 - Within ”moments” of the Supreme Court decision, the National government signaled its intention to change the law in order to build the dam.
7. Oct 2017 – Labour won the election and took over the central government before National could change the law.
8. Jul 2018 – HBRC decided to drop the project and sold its rights in it for NZ$100,000.

US-NZ GW Comparisons

Item	US	NZ
1. Aquifer size	Small to v. large	Small
2. Tertiary education	MS-Ph.D. hydrogeo.	None
3. Std. procedures	Many (EPA, ASTM…)	2006 NGMP & 2010 Q only
4. National laws	Many (SDWA, RCRA…)	RMA only
5. Quantitative stds.	Many (EPA, state…)	DW only
6. Report writing G/Ls	Many (Pro., EPA, state…)	None
7. Monitoring wells	Designed/dedicated	Mainly farm wells
8. Age dating water	Not widely done	Widely done for pub. DW 0.005 % < 1 year age

GW Comparisons (p.2)

Item	US	NZ
9. RR lysimeters	Rare	National program
10. Hydrologic res	Integrated GW-SW	Separate programs
11. Admin. processes	Open to public	Discretionary
12. Climate change	Lack of national policy	National policy
13. Professional codes	Yes (states and orgs)	No
14. GW modeling	Substantial data	Sparse data
15. Reinventing wheel	To some degree	Often
16. Use outside info	Usual procedure?	Limited (e.g., DWS consider WHO)
17. Political system	States > Central	Central > Regional C.


"That's all Folks!"