



Manaaki Whenua
Landcare Research

EM mapping

A precision tool for soil mapping and strategic land management

Carolyn Hedley

- Carolyn Hedley is a Soil Scientist with Landcare research currently studying EM and other proximal sensing methods that could be used to map soil properties.
- In this presentation she makes the link between Electro Magnetic properties of the soil and Soil Water Availability. This is extremely important in terms of working out productive potential of an area of land and calculating the optimum irrigation strategy for different areas of a farm.

Objectives of presentation

- Overview of electromagnetic (EM) and electrical sensors used for mapping landscapes.
- Farm-scale sustainability issues
 - coping with soil variability
 - maintaining soil quality
 - irrigation water usage
 - storm damage
- Conclusions

- **AIRBORNE - good for large aquifer studies but not soil imaging.** Such devices must **strip out the effect of instrument altitude from the data, which makes it impossible to accurately image topsoil.** Usually data is only reliable 10m beneath surface. Some airborne systems can see **100s of metres into the ground** but cannot simultaneously resolve shallow and deep features.
- PHOTO = skyTEM.com (Denmark) = SkyTEM a time domain transient electromagnetic (TDEM) method used for environmental investigations, mineral explorations and other resistivity studies.
In Australia it is used for **imaging aquifers.**
- **GROUND-BASED** – useful for **mapping soils, with an effective depth to about 1.5m.** EM and electric sensors are the most extensively used ground-based (OR PROXIMAL) sensor used for assessing soil variability at the farm-scale, at the present time. Other sensors include optical and radiometric, mechanical, acoustic and electrochemical sensors.
 - optical and radiometric – measure reflectance, absorption or transmittance
 - Mechanical – e.g. soil strength measured by mechanical resistance (e.g. penetrometer)
 - Acoustic and pneumatic – correlated with soil texture and compaction (e.g microphone or air-pressure transducer)
 - Electrochemical – direct evaluation of soil fertility by e.g ion-selective electrode or transistor. Measured voltage between the sensing and reference part of the system is related to concentration of specific ions (H⁺, K⁺, NO₃⁻). Adamchuk has developed an on-the-go DIRECT SOIL MEASUREMENT + GPS FOR pH. A soil sampling mechanism scoops a soil sample and brings in contact with the electrode. After a stable reading is measured the electrode is rinsed before the next reading.
- PHOTO = NZCPA equipment for EM mapping, using a Geonics EM38, Polycorder 600 data logging system, Trimble Ag214 RTK-GPS and Trimble Ag170 field computer.

EM mapping



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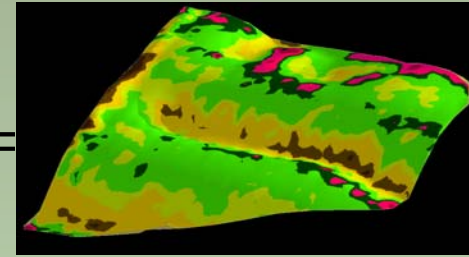
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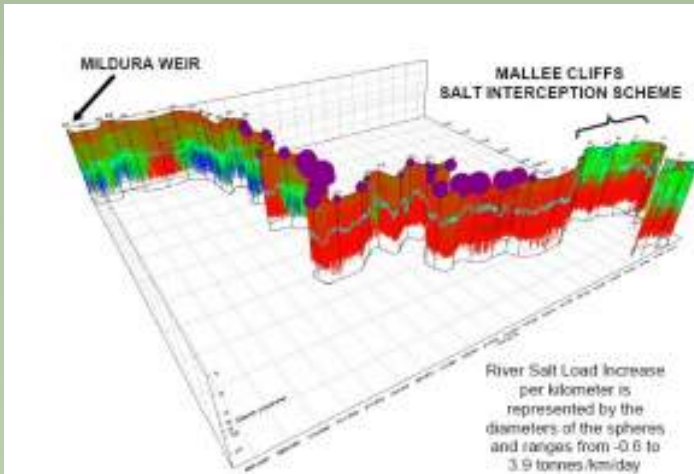


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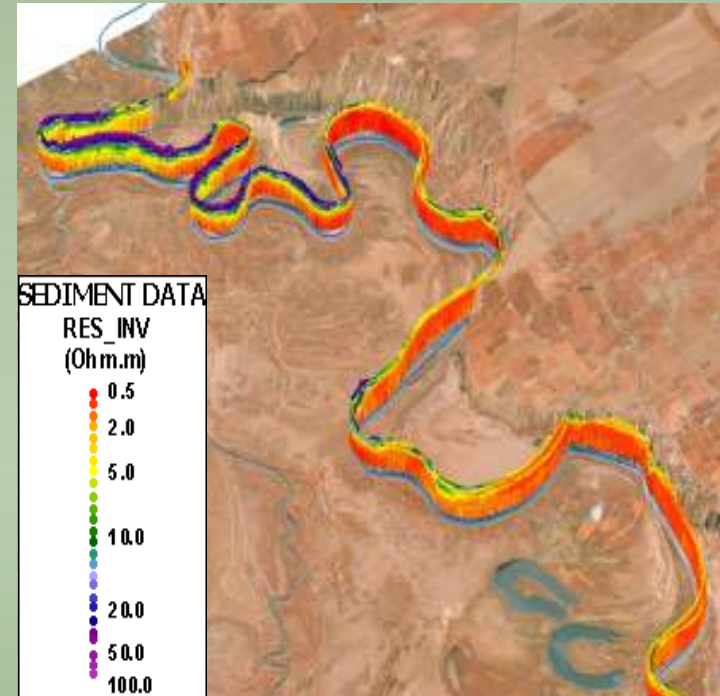
- EM mapping: airborne, waterborne and ground-based
- **WATERBORNE** – TRANSMITTER AND RECEIVER LOOPS ARE MOUNTED IN A PVC FRAME ON A FLOATING PONTOON - useful for **imaging surface and groundwater systems**, providing **information required to manage these resources**. It is used in Australia to map **saline, acid** (from acid sulphate soils) and **other pollution inflow into rivers**.
- PHOTO = Volmer Berens, 2004 = a towed NanoTEM array, used in the project monitoring salt accession to the Murray River in South Australia. Soundings every 5 to 10 m. Vegetation clearance and irrigation practices have increased recharge to underlying aquifers. Localised GW mounds have formed beneath irrigation regions, displacing deeper saline water towards alluvial sediments and seepage zones, with resultant discharge to rivers (SALT ACCESSION). The excess water pressurises the deeper aquifers, causing upward leakage of saline water into alluvial sediments and eventually into rivers. Transmitter and receiver loops are mounted in PVC frame on a floating pontoon and data acquired every 4 seconds at an average boat speed of 5km/hr, resulting in a TEM reading approx every 5m.
- Data is handled using **an inversion process** (sensitivity matrix of coefficients, an algorithm, and iterative least squares optimisation technique) to model to data as resistivity with depth

EC maps - rivers



EC ribbon plot below the Murray River, upstream of Mildura, NSW, showing salt accession.

**Allen & Merrick, 2005,
National Centre GW
Mngmt, Sydney**



River-borne nanoTEM survey for salt accession to River Murray at Loxton, SA.
**Berens, 2005, Dept Water Land &
Biodiversity Conservation, Australia**

- **Water-borne EM DEVICES enable mapping of surface waters.**
- **Both Ribbon plots show saline inflow into the Murray River.**
- EM devices are towed along watercourses to image EC at multiple depths within and beneath watercourses. EC is typically related to GW salinity and secondly to clay content.

EM Mapping - land



Geonics EM38 **0 ~ 1.5 m**



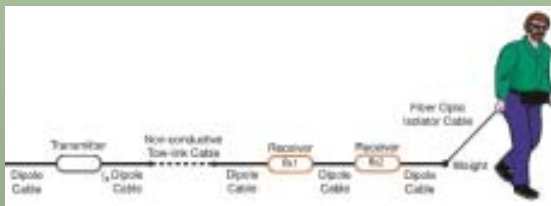
Geonics EM31 **0 ~ 5 m**



Geonics EM34 **0 ~ 10 m**



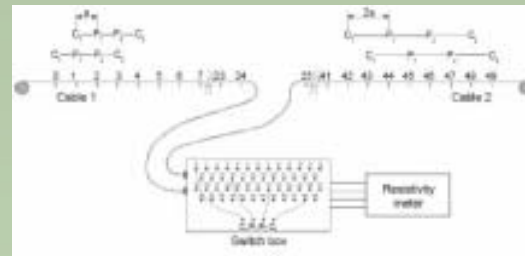
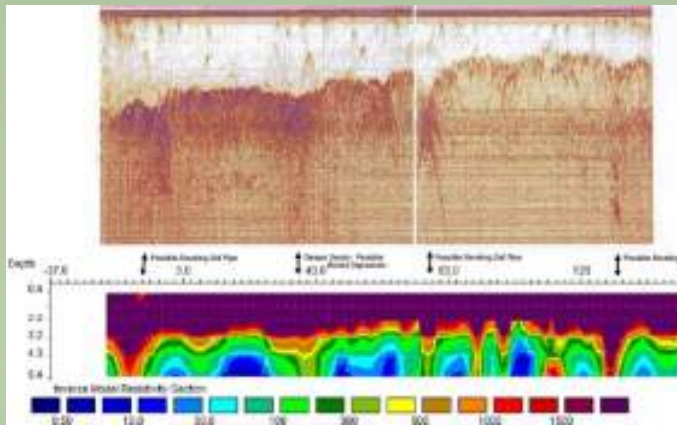
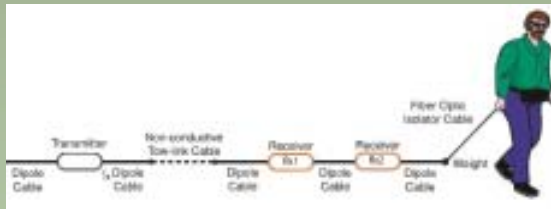
Geonics EM39 **borehole**



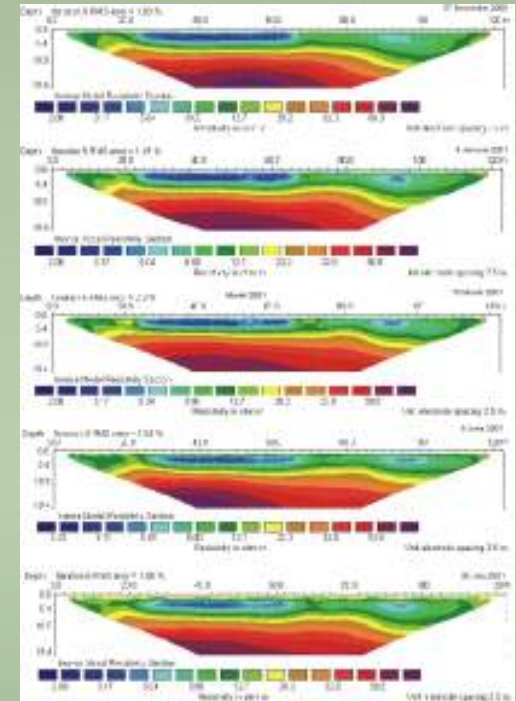
Geometrics OhmMapper
electrical imaging

- The depth of measurement depends on distance of separation of transmitter and receiving coil – and a range of sensors are available for assessing EC to different depths
- Electrical imaging (tomography) involves measuring along a line of electrodes. Increased separation of electrodes gives greater depth penetration so EC can be measured simultaneously at a range of depths.

Electrical Imaging



Depth (m)	Resistivity (ohm-m)	Apparent Resistivity (ohm-m)
0.0	100	100
0.1	100	100
0.2	100	100
0.3	100	100
0.4	100	100
0.5	100	100
0.6	100	100
0.7	100	100
0.8	100	100
0.9	100	100
1.0	100	100
1.1	100	100
1.2	100	100
1.3	100	100
1.4	100	100
1.5	100	100
1.6	100	100
1.7	100	100
1.8	100	100
1.9	100	100
2.0	100	100
2.1	100	100
2.2	100	100
2.3	100	100
2.4	100	100
2.5	100	100
2.6	100	100
2.7	100	100
2.8	100	100
2.9	100	100
3.0	100	100
3.1	100	100
3.2	100	100
3.3	100	100
3.4	100	100
3.5	100	100
3.6	100	100
3.7	100	100
3.8	100	100
3.9	100	100
4.0	100	100
4.1	100	100
4.2	100	100
4.3	100	100
4.4	100	100
4.5	100	100
4.6	100	100
4.7	100	100
4.8	100	100
4.9	100	100
5.0	100	100
5.1	100	100
5.2	100	100
5.3	100	100
5.4	100	100
5.5	100	100
5.6	100	100
5.7	100	100
5.8	100	100
5.9	100	100
6.0	100	100
6.1	100	100
6.2	100	100
6.3	100	100
6.4	100	100
6.5	100	100
6.6	100	100
6.7	100	100
6.8	100	100
6.9	100	100
7.0	100	100
7.1	100	100
7.2	100	100
7.3	100	100
7.4	100	100
7.5	100	100
7.6	100	100
7.7	100	100
7.8	100	100
7.9	100	100
8.0	100	100
8.1	100	100
8.2	100	100
8.3	100	100
8.4	100	100
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8.6	100	100
8.7	100	100
8.8	100	100
8.9	100	100
9.0	100	100

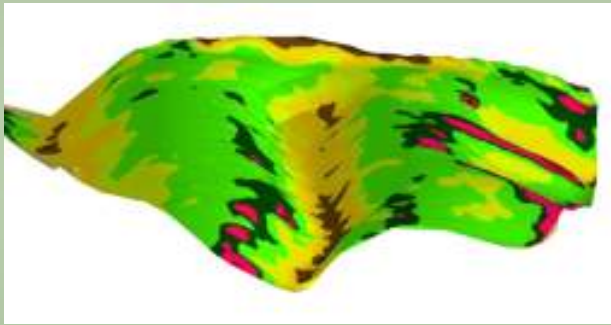


Comparison of ER to GPR.
Silica sand over limestone.
GPR vertical scale 9m. ER
vertical scale 5.5m using a
USDA OhmMapper
Geometrics.com

Irrigation monitoring of long
fallow, perennial grasses,
lucerne and short fallow,
Nov – July
Ackworth, AJSR, 2005

- This can then be used to construct a **vertical and lateral contoured section**.
- 2 examples:
- The first is a comparison of a soil profile image using GROUND PENETRATING RADAR with an ELECTRODE ARRAY RESISTIVITY method. It shows that the ELECTRODE ARRAY RESISTIVITY method can provide a very accurate image of a soil profile. **USDA OhmMapper (www.geometrics.com)**
- Also using an electrode array. Work by Ian Ackworth (Water Res Lab, NSW, Aust) uses electrical (resistivity) (inverse of conductivity) imaging for irrigation monitoring. A series of electrodes are attached at regular intervals (perhaps every 5m) along a cable which can be several 100m long. ER is measured between electrodes at different spacing - the separation between electrodes (or coils) determines the volume of material sensed by the instrument – an increased spacing provides information at increasing depths. Approx depth of this zone is half the electrode separation.
- The plots reflect water use by different surface covers (lucerne buffer, long term fallow, perennial grasses, lucerne, short fallow) over an 8 month period. Blue zones in surface 3m are low ER (i.e highest EC) and therefore wettest. These relate to the long term fallow landuse. The lucerne crop is extracting most water. Neutron access tubes were used to record mc, and a correlation of 0.77 suggests that electrical imaging can be used to satisfactorily predict bulk mc in these soils. The plots show drying of the soil profile to 6m depth beneath lucerne.
- The success of lucerne is dependent upon its ability to create a zone of dry soil below the normal rooting depth of annual crops that acts as a buffer against water leakage from the soil to groundwater. Depth of rooting 1.7m.

EC mapping - land

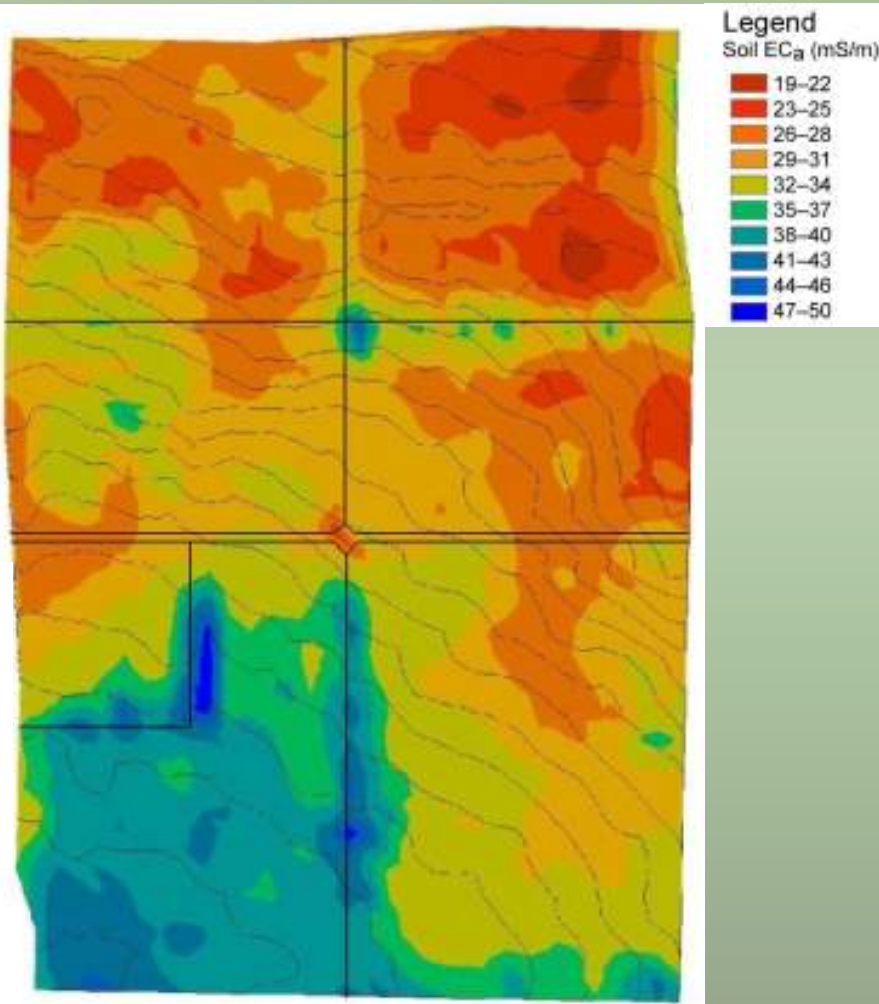


EC map of rolling downland, Temuka, Canterbury, NZ, showing topsoil erosion on ridges exposing finer textured clay subsoils (NZCPA)

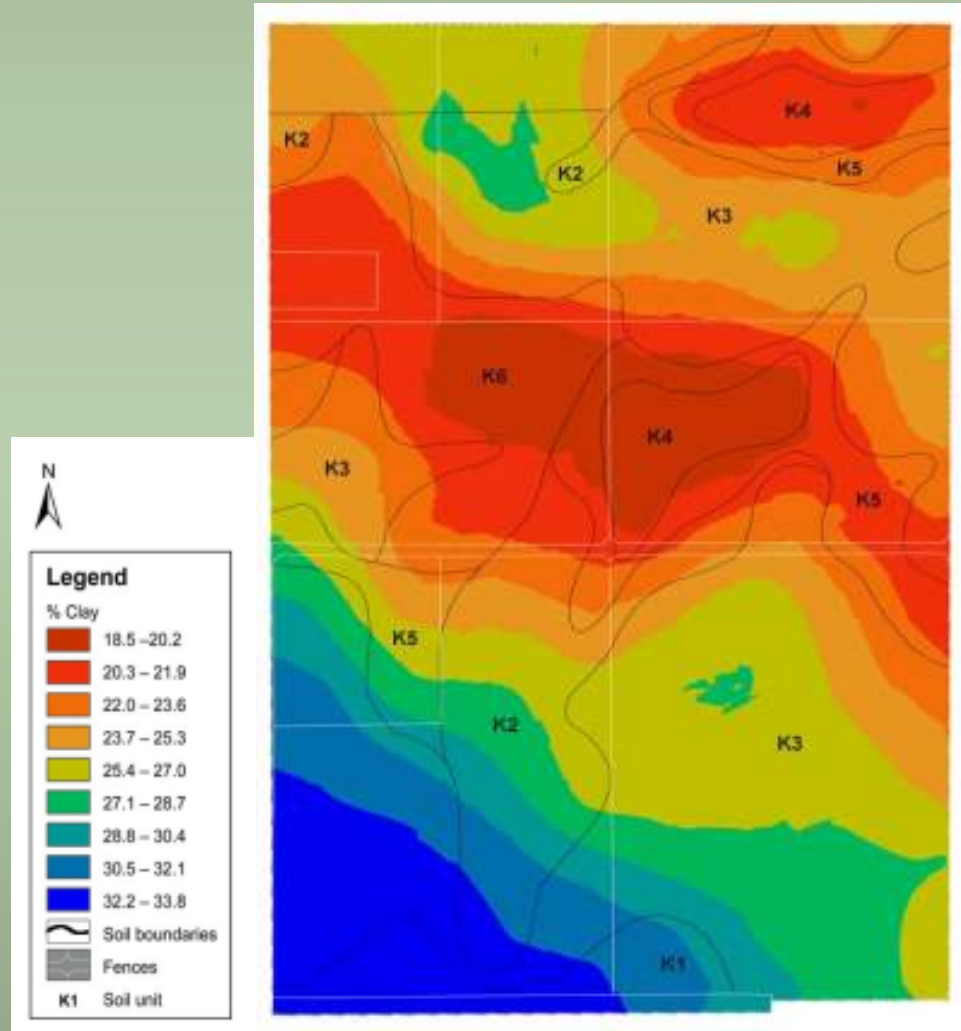
EC mapping - land



EC map

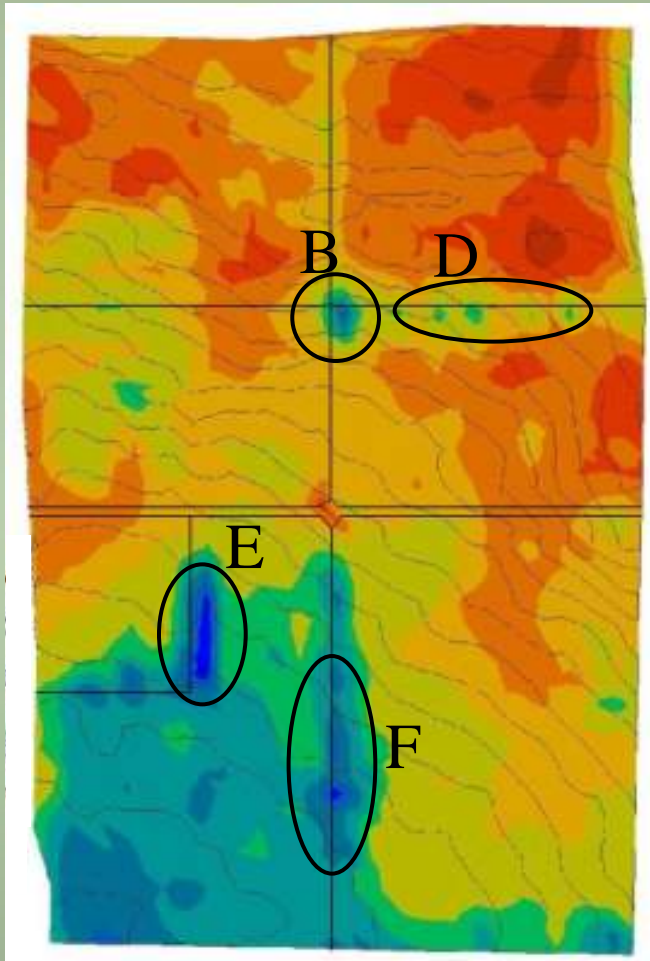


Soil clay map



- So what exactly is the EM map showing us and how does it relate to soil properties.
- On the left is the EMI map produced. On the right is a map of percent clay weighted to 1.2m for the soil profile. The EMI map depicts the heaviest textured soils in the bottom corner of the study site grading to coarser textured soils closer to the river. The conductivity range is from 19-50 mS/m. Percent clay (weighted for the soil profile) ranges from 18% to 33%.
- We can see that the EM map provides a very good indication of the soil textural groupings in this area.
- **Some of the differences between the maps arise from different resolution. The clay map is kriged from 126 data points (approx 40m apart) and is less spatially precise than the EM map.**
- **The EM map is produced from continuously logged data points – every second (that’s approx 1200 points), which were then kriged (using a 5m radius) using Spatial Analyst software.**
- Having compared soil clay we were interested to relate the EM map to some other soil properties.
- Rigorous text – because the soils are all of one soil type – Kairanga silt loam, with 6 textural phases.

EC map highlights areas of soil with (i) compaction and (ii) degraded soil structure



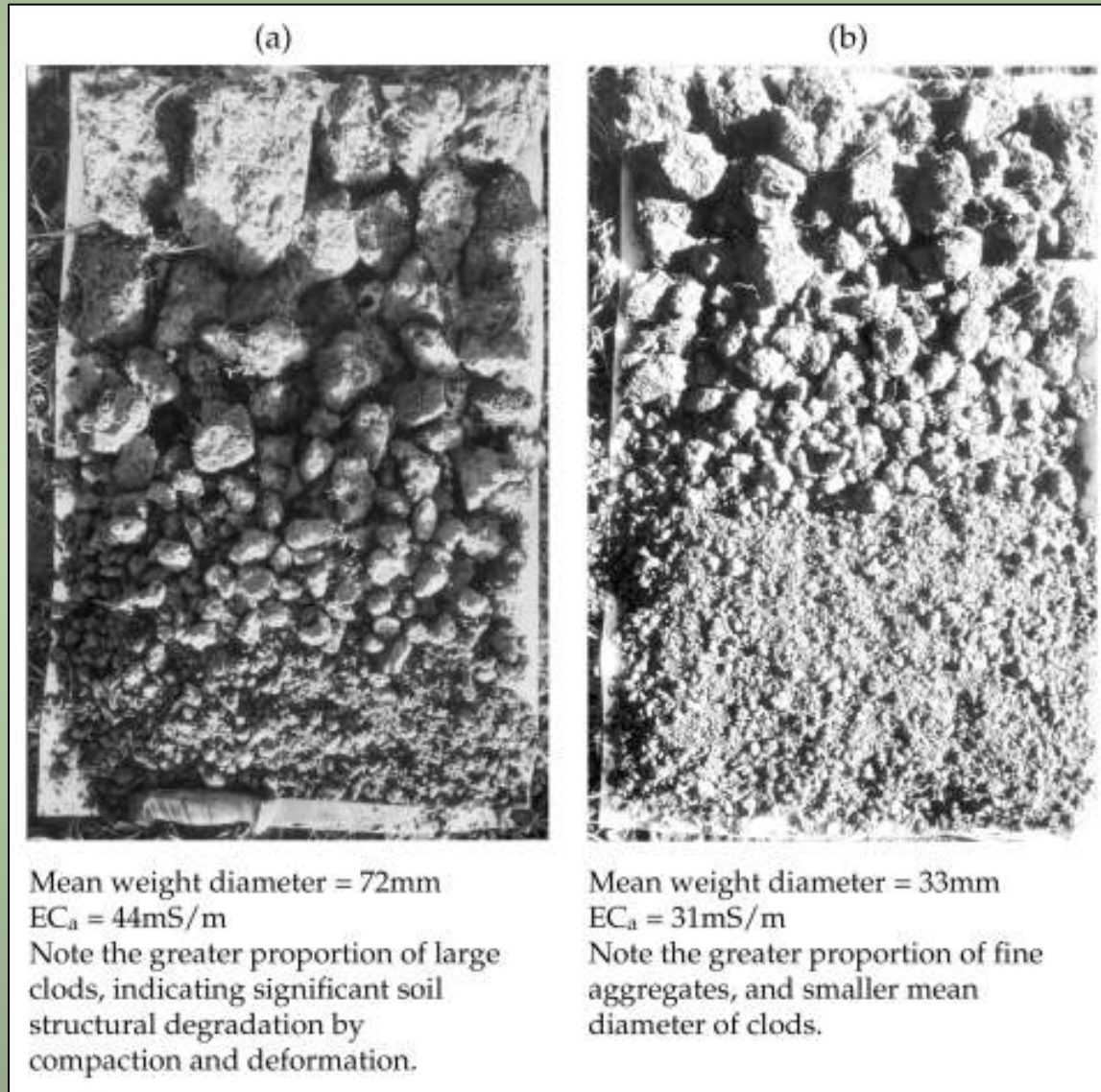
Site	EC _a mS/m	Soil strength (0-50 cm) MPa	Worm count	Aggregate size mm	VSA Score
B	44	2.96	108	72	8.2
	31	2.63 *	1083 ***	33 *	17.5 ***
D	44	3.49	333	58	13
	31	2.63 ***	1083 *	33 *	17.5 ***
E	48	2.12	8	53	12.5
	37	2.12	25	33	16 ***
F	48	2.89	475	49	13.5
	37	2.75	667	25	20 **

* p value <0.05 ** p value <0.01 *** p value <0.001

5 minute worm count of a 200 mm block of soil

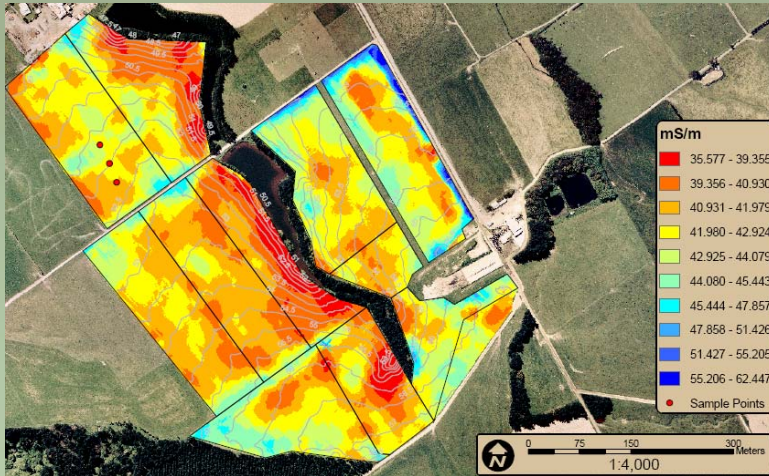
- On the second map 4 sites with localised elevated ECa values were investigated. Two of them showed signs of compaction. All four sites had VSA scores significantly lower than the surrounding soils. This means that in these zones of elevated ECa soil structure has been degraded, structural units are larger, porosity is decreased and earthworm numbers were reduced. This all points to soil structural degradation due to such practices as pugging (in gateways) over-cultivation (in headland areas) or stock treading.
- It is likely that the elevated ECa values are related to improved conducting pathways between soil particles, due to this structural degradation.

VSA of “hot spots” on EM maps confirms that these are zones of degraded soil structure

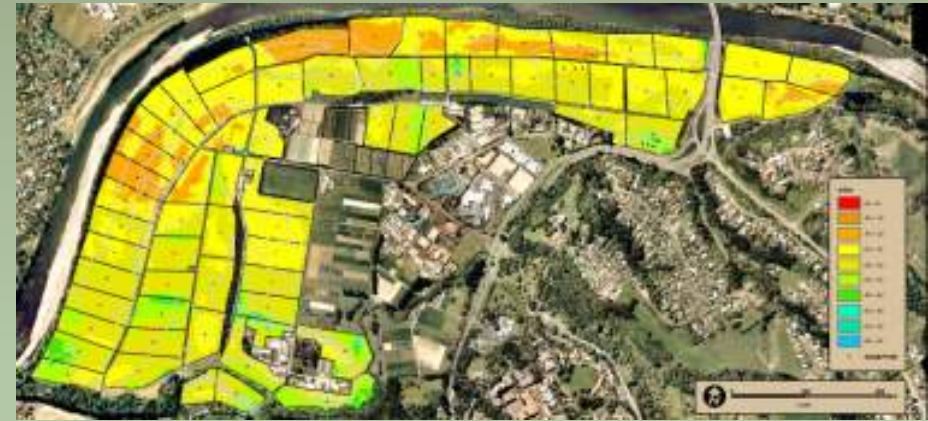


- This shows an example of one site – where a zone of elevated ECa is compared with the surrounding soil.
- The figure on the left shows a soil with a greater proportion of large clods, indicating **significant soil structural degradation by compaction and deformation**. It has an ECa value 14mS/m greater than the soil on the right, which can be seen to have a greater proportion of fine aggregates and smaller mean diameter of clods.
- INFORMATION FOR NEXT SLIDE
- 3 EXAMPLES-
- 3 properties – Massey University Dairy 4 (on Tokomaru si lm), Massey University Dairy 1 on coarser alluvial soils and Dannevirke dairy farm on shallow terrace soils over gravels (Takapau) and finer, deeper alluvial soils close to the river.
- Classification units are standardised – so that we can compare the 3 properties. (Each unit has a range of 5mS/m.) Tokomaru si lm at Dairy 4 is very uniformly textured – so little differentiation using these divisions. Finest textured soil – typically 40 to 50 mS/m. The alluvial soils at No1 typically occur in the range 20 – 30mS/m Gravel ridges with thin mantles of soil – 10mS/m. Dannevirke alluvial soils are similar range. The Dannevirke farm Takapau soils have low EM values, 10 – 20mS/m

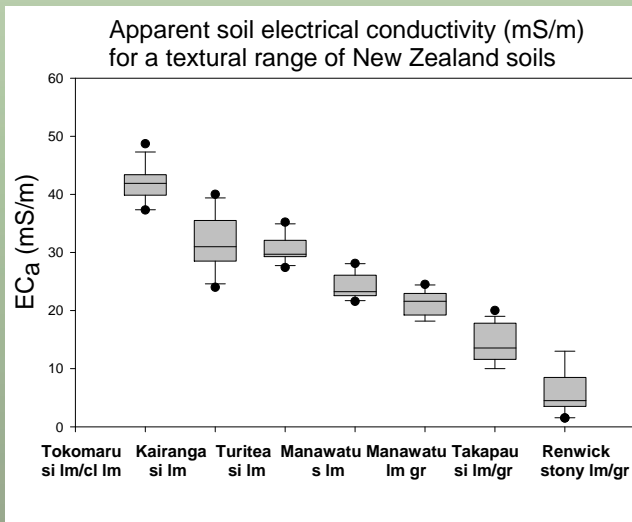
EC mapping = rapid farm-scale soil mapping



35 – 65mS/m
 Massey University
 No.4 Dairy Farm
 Tokomaru silt loam, poorly drained



10 – 55mS/m
 Massey University No.1 Dairy Farm
 Alluvial Manawatu and Rangitikei soils



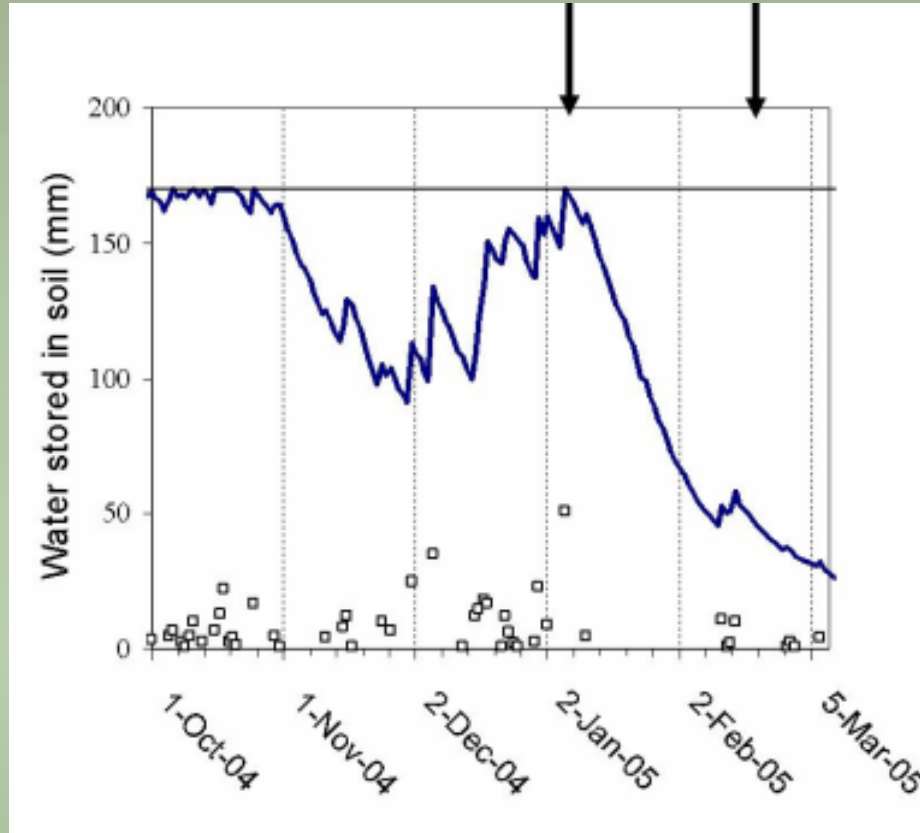
5 – 35mS/m
 Dannevirke Dairy Farm – shallow terrace soil on gravel, and deeper alluvial soils



- EM maps show soil variability on a basis of texture
- CLICK 1- Now if we want to look at Dairy 4 in more detail – use a NARROWER range for each classification unit – looks like this – now we can see something quite different – areas of compaction and more freely draining areas – just by software manipulation of the data. THE MORE FREELY DRAINING AREAS RELATE TO AREAS WHERE MOLE DRAINS HAVE RECENTLY BEEN RENEWED, AS WELL AS AREAS WHERE THE LAND SLOPES DOWN TOWARD THE LAGOON – AIDING DRAINAGE OF SOILS IN THESE AREAS.
- Therefore EM is a good indicator of soil texture - and this graph shows that each soil type has a characteristic range for EM depending on soil moisture (between saturation and very dry).
- So - looking at the No1 Farm EM map - EM is related to soil texture and soil moisture. Soil water holding characteristics depend on soil texture and structure. Therefore can EM mapping be used to assess soil water holding characteristics? 30um – 0.2um pores=FC-WPt; **Silt loam 0.36-0.14=0.22AWC(v/v)**
- The EM map shows areas likely to be droughty or have excess water problems. What we need to know is the AMOUNT OF WATER THESE SOILS CAN HOLD i.e their **AVAILABLE WATER HOLDING CAPACITY (WHICH IS MEASURED IN MM WATER/CM DEPTH FOR IRRIGATION PURPOSES).**

Soil sampling

Intact soil cores
extruded onto a
liner for
subsampling



**Giddings hydraulic
corer used to
extract intact soil
cores to 76cm**

WEIGHTED MEAN MC_v to 76cm

So having produced an EM map we assessed volumetric soil moisture to 76cm, using a hydraulic corer on the back of a one tonne truck. This enables intact cores to be sampled to depth, which can then be analysed for bulk density and moisture content.

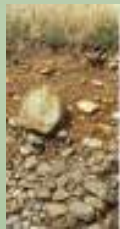
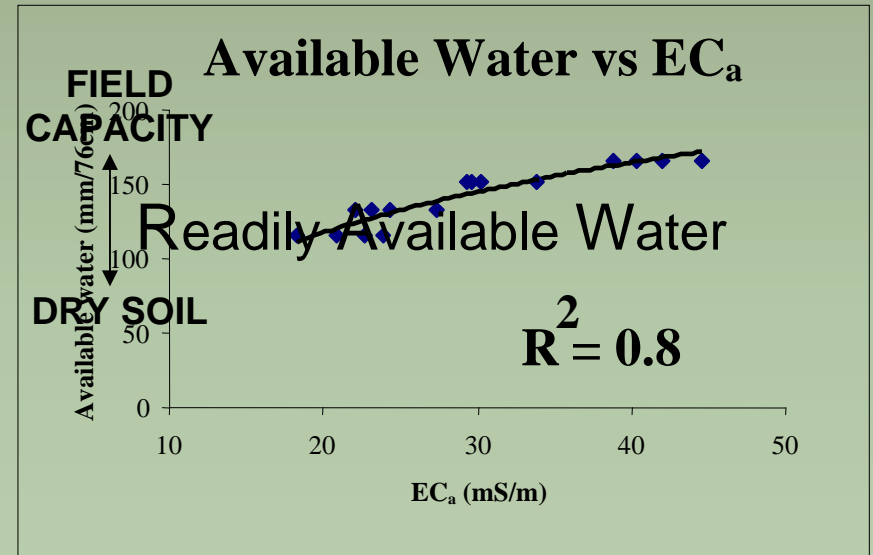
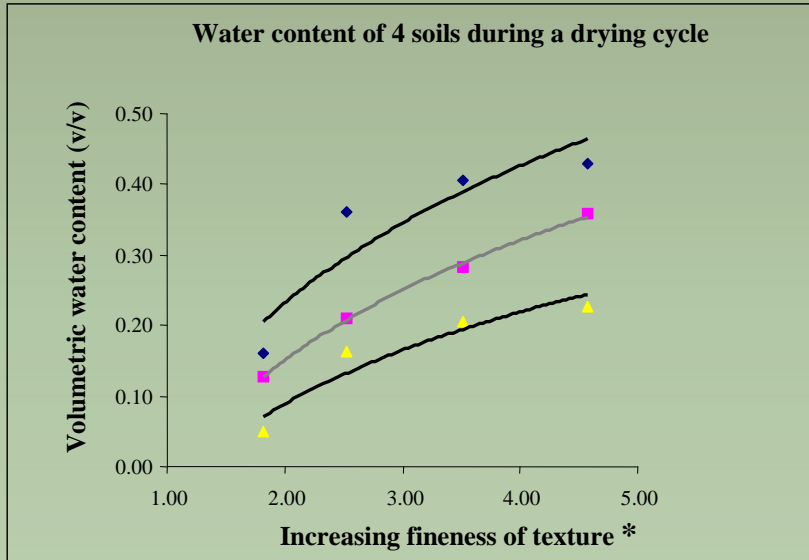
Sites were selected in contrasting soil types which represented the widest textural range from silt loam to loamy gravel. 3 replicate sites within each soil type. Then volumetric mc was assessed at Field capacity, an intermediate soil moisture, and when the soils were very dry (just prior to irrigation commencing).

FC = 0mm SMD

EM survey = 61mm SMD

Very dry = 107mm SMD

Using EM to spatially predict available water



coarse
texture



fine
texture



coarse
texture

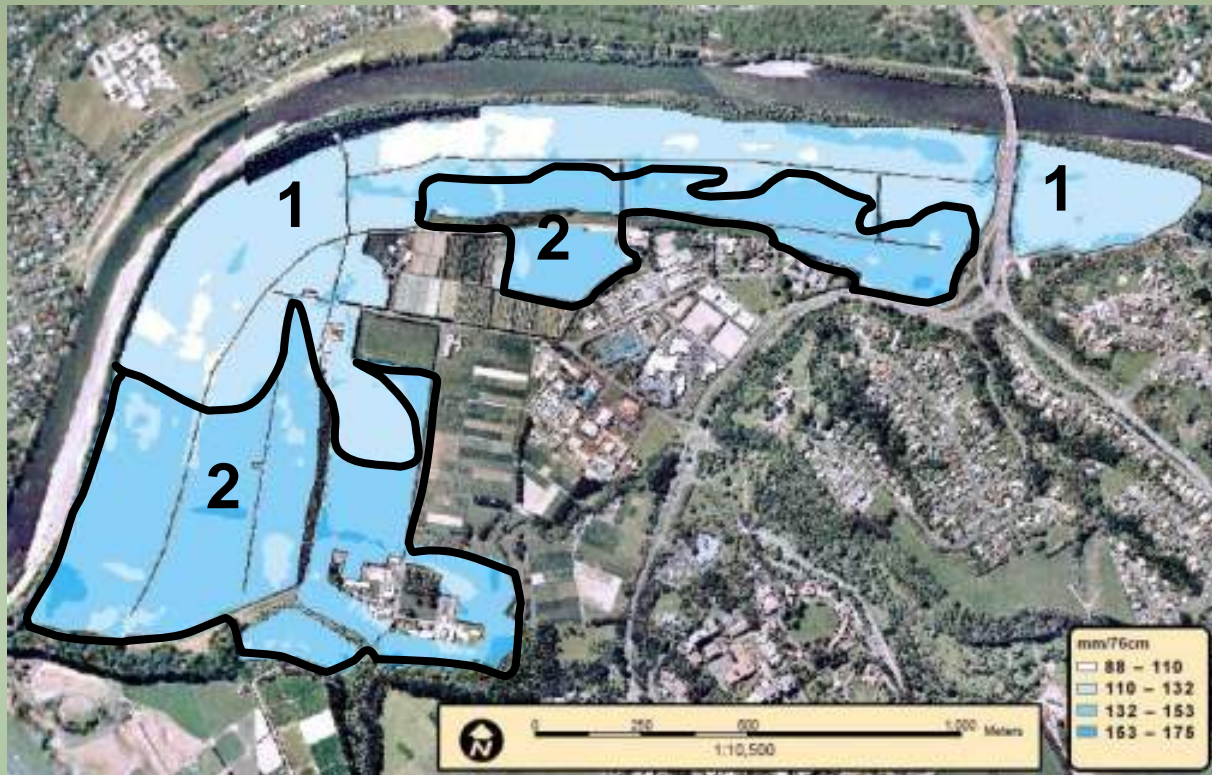


fine
texture

* Fineness class (Waine, Blackmore & Godwin, 2000)

- **Texture-moisture curves** were developed at a range of soil moistures, from FC (deficit of 21mm, R of 51mm, drained 24hrs) to very dry (SMD 107mm). **Texture was quantified using a “Fineness Class” developed by Waine et al (2000, at Silsoe).** The fineness class ranks the 11 main texture classes (defined on the texture triangle) in order of increasing fineness between 1 and 6 in 0.5 intervals. A texture weighting equation is used ($0.03\% \times \%cl - 0.004 \times \%s$) developed as a best fit relationship ($r^2=0.99$).
- The graph shows: (1) in general soils of increasing textural fineness will hold more water, and (2) shows the difference in volumetric water content for each soil over a drying cycle from close to FC to end of a long dry period, just prior to irrigation being used on the farm.
- The difference between these 2 curves is therefore an estimate of the amount of available water that the soil can supply to a plant – close to RAW – a measurement made in the field (NOT lab based).
- This is then related to EM for each time the soils were assessed.
- Graph 3: So for each soil, within this textural range, we have an estimated AWC, vol wc and measured EC. Graph 3 shows the relation of AWC to EC found in this study. This relation can then be used to spatially define available water in this study area.
- Log relationship spreads out skewed data – inverse of exponential i.e. decreases rapidly at low end.

Available Water Status Map of No.1 Dairy Farm, Massey University



Schedule irrigation more frequently for Zone 1

Keep water in the active root zone

Match irrigator to scale of delivery required:

K line ~ 25m²

Centre pivot ~ 50 – 100m²

Travelling irrigator ~ up to 5000m²

MfE document: **“Management of Freshwaters”** Dec 04

“Our freshwaters are under pressure” “need to set priorities”

“significant agricultural growth is supported by irrigation. The area of irrigated land has roughly doubled every 10 years since 1960s, and irrigation now accounts for nearly 80% of all water allocated in NZ”



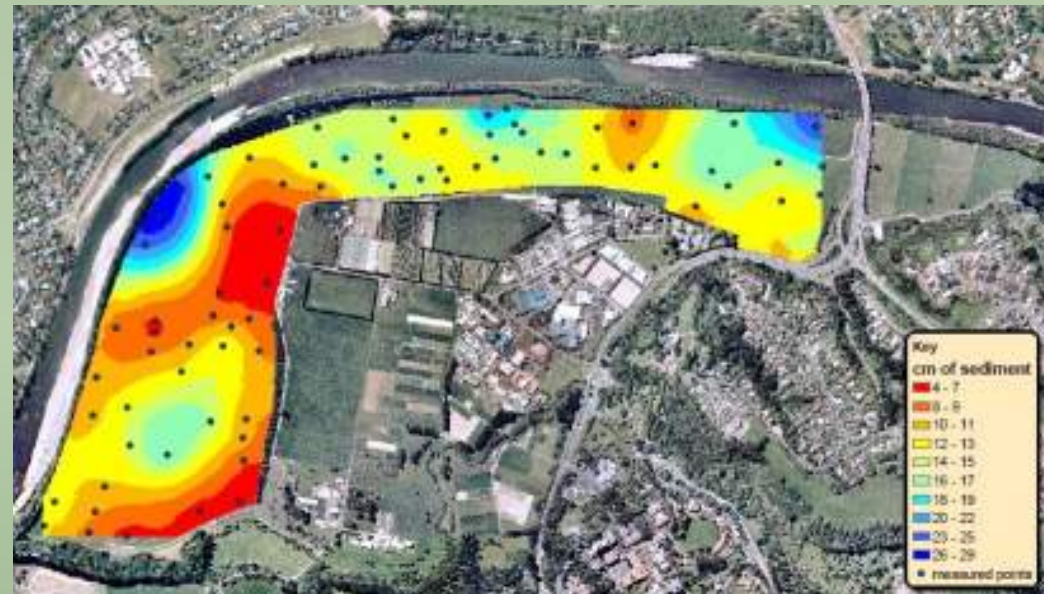
- Added value to the EM data. We now kriged a map showing the spatial distribution of soils related to their available water holding characteristics.
- This is a management tool for the farmer when scheduling amounts and rates of irrigation water usage.
- (WATER TRADING IS ON THE HORIZON)
- Example: \$700 - \$1000/day pumping water
- 2 management zones: no.1 requires 90 -130 mm water and no.2 requires 130 – 175 mm.
- **HAPPY FARMER AND HAPPY ENVIRONMENT**
- **Irrigating pasture:**
- **Target 76cm soil depth**
- Irrigation rate: **5mm/hr**
- Irrigation unit: **1mm depth=1L/m²=10m³/ha**
- **RURAL PAPERS ARE STARTING TO TALK ABOUT WATER TRADING**
- MfE document: **“Management of Freshwaters”** Dec 04
- “Our freshwaters are under pressure” “need to set priorities”
- “significant agricultural growth is supported by irrigation. The area of irrigated land has roughly doubled every 10 years since 1960s, and irrigation now accounts for nearly 80% of all water allocated in NZ”

Storm damage



Floodwaters on Massey University No.1 Dairy Unit, Feb 16, 2004

Map to show depth of flood deposits. Approx. volume of sediment deposited in the 100+year storm was 106,000m³.



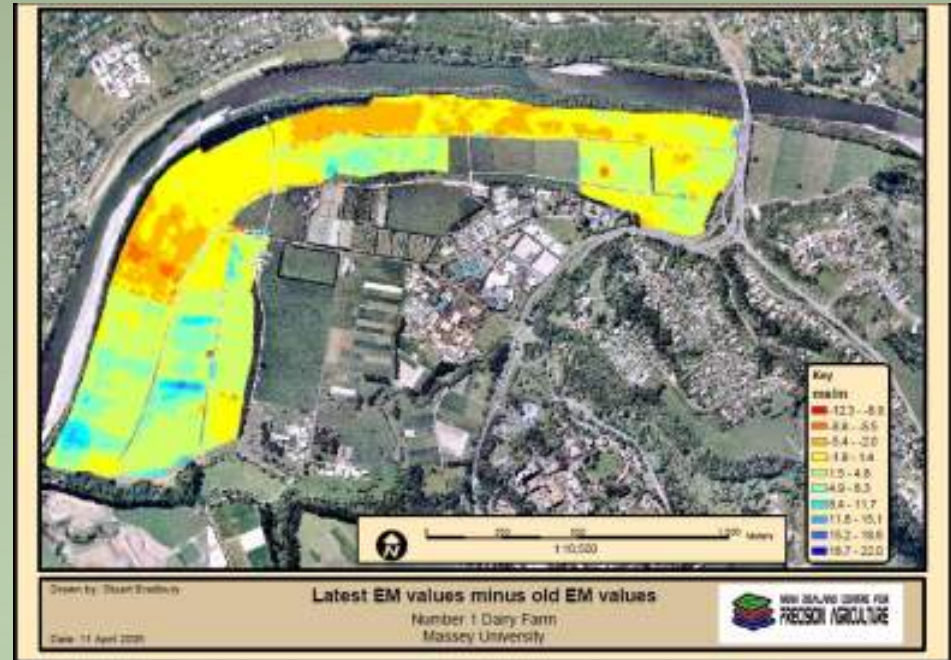
Data collected by J A Pollok, kriged by S. Bradbury

Floodwaters deposited sediments up to 40cm thick. Each marked point is where Jim recorded depth and texture of fresh sediment. ArcMap software is used to krig the data points into a map. It also provides statistics ie % areal cover of each category – so if the total farm area is known it is simple to calculate the depth of sediments deposited in this one flood event – 106,000m³

Soil change due to storm damage



August 2003



Conclusions

- EM sensors can be used to map soil pattern and variability – intrinsically linked to crop yield, agricultural productivity and sustainability.
- The relationship between EC, soil texture and moisture can be used to produce a map of soil available water at the farm-scale, a useful tool for scheduling irrigation water use.
- Ground-based sensors (e.g. EM) enable environmental monitoring and mapping, at a scale and sampling density previously unobtainable. They provide information for fine-tuning management practices and optimising use of natural resources (e.g. soil and water). This in turn helps to sustain agricultural systems for future generations.

