Attachment 1

A pilot study evaluating the effects of solar panel leachates on highly productive lands, and the implications for other ecosystems.

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Abstract.
The types of contaminants in soils at Brookside (Canterbury, New Zealand) replicated the materials found in solar panels placed above ground. The long-term impacts of those contaminants on soil compaction, colonies of soil microorganisms, the composition of plant communities, the uptake of contaminants by plants, the bioaccumulation of contaminants in terrestrial vertebrates, and the potential for those contaminants to be washed into aquatic ecosystems are discussed.

'Test' soil samples were taken from under polycrystalline solar panels at Brookside by Ravensdown and compared by Analytical Research Laboratories Ltd. with 'control' soil samples taken from the same soil 40-m distant from panels. Results showed that in soils under solar panels after 9 years sodium was up 33%, nitrate-nitrogen was up 40%, iron was up 72%, the sulphates/sulphides of metal leachates were up 333%, copper was up 22%, cobalt was up 13%, magnesium up 14%, manganese up 14%, boron up 17%, cadmium up 29.5%, arsenic up 27%, aluminium up 5%, and lead up 22%. To these added concentrations of heavy metals in soils must be added leachates from panels that have bioaccumulated in plants. High levels of iron, aluminium, manganese, copper, and lead were found in ryegrass.

The increased sodium ions are an indication of micro-cracks developing during the breakdown of antireflective coatings (ARC) and the outer layers of polycrystalline panels. These are deposited on soils as sodium nitride and silicon nitride (Komatsu *et al.* 2018, Dong *et al.* 2018). These things explain the increase of sodium and nitrogen in soils. Following the development of these micro-cracks, the semi-conductor pyrite (FeS_2) is released from panels and deposited on soils where it is degraded in a reaction with oxygen and water ($FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 4H^+ + 2SO_4^{2-}$) to add more sulphates than iron to soils as shown in the soil test. At this early stage in the field-life of panels, the iron in soil (2,040 mg/kg) and plants (98 mg/kg) combined has more than doubled under panels. The H^+ ions released in the chemical reaction outlined above and hydrolysis of aluminium have increased soil acidity from pH=6.6 to pH=5.9. As the panels further degrade, they will increasingly leach conductors from the panels in the form of tin, indium, magnesium, manganese, boron, zinc, cobalt, copper, arsenic, cadmium, lead, and aluminium (the latter 5 are especially toxic in an aquatic environment; Aziz *et al.* 2023).

The solar panels have altered standard measures of soil fertility (NPK) by increasing leached nitrogen (N) and lowering phosphorous/phosphates (P) and potassium (K). The increased nitrogen (mainly in the form of nitrate-nitrogen) was up 40% below panels which increased ryegrass growth between panels, whereas leached heavy metals have killed clovers. The progressive increase of aluminium and iron facilitates soil flocculation and contributes to soil compaction (Mazurana *et al.* 2017), that may eventually lead to a hard compacted soil surface and the development of an iron at the clay-loam interface in the soil substrate (Cunningham *et al.* 2001). The hard compacted soil surface will increase run-off of floodwaters. Added heavy metals within soils (especially Fe, Al, Cu, Cd and As) are known to destroy soil micro-organisms, and reduce populations of earthworms.

When concentrations of iron (Fe) increase beyond the 'trace amounts' required for plant growth it causes bronzing of plant leaves and stunted growth (Marzorati *et al.* 2022). This phenomenon can be seen in the dripline under polycrystalline panels and where iron pyrites has run down panel supports. Excess iron in heavy soils not only contributes to soil flocculation and soil compaction, but significantly reduces the abundance and types of soil micro-organisms (e.g., Zhang *et al.* 2022). Iron (Fe), aluminium (Al), and copper (Cu) especially have destroyed the mycorrhizae on clover roots, reduced uptake of phosphate and potassium and eliminated clover from under and around panels. Ryegrass (var. Nui) readily grows in the vicinity of solar panels because of high levels of leached nitrates, and this accelerated plant growth bioaccumulates heavy metals. Heavy metals that bioaccumulate in ryegrass are ingested by sheep and impact animal health and animal welfare.

The implications of these findings for other types of solar panels situated elsewhere are self-evident. Wherever solar technologies are situated, contaminants of materials used in those technologies progressively leach during the weathering process, they accumulate on soils, and are then washed into streams as part of stormwater. Other types of panels with different heavy metals and PFAS have been demonstrated to seriously impact aquatic ecosystems offshore, they contaminate groundwater, change soils, bioaccumulate in plants, and bioaccumulate in the food webs of animals. Contaminants from solar panels change plant communities growing on soil (e.g., Bai *et al.* 2022) and reduce the productivity of land (ADAS 2023, Choi *et al.* 2021).

Introduction.

Many people believe the drawbacks of converting agricultural land to 'utility scale solar power' (USSP) facilities is circumvented by combining farming and solar energy generation: a practice now referred to as agrivoltaics. Unfortunately, to date there have been no long-term studies on the cost-benefits and environmental risks of agrivoltaics. The submission for resource consent for a solar farm at Brookside contained photos and an analysis done by an agronomist that outwardly suggested that the construction of a solar farm would improve the productivity of lands because of a "changed micro-climate between panels". This was contrary to all the empirical data from published literature. Therefore, soil and vegetation samples were taken from under similar solar panels on a neighbouring property with a similar solar farm to quantify the risks of these panels to: a) the productivity of soils, b) to vegetation growing on soils near solar panels, and c) to the aquatic ecosystems surrounding solar technologies.

Solar technologies are made almost entirely of a class of compounds known as "forever chemicals". These include heavy metals, and per- and poly-fluoroalkyls (PFAS) that do not degrade in soils or water. The materials have a propensity to bioaccumulate in living organisms (plants and animals) because they have a long half-life in tissue. When ingested in chronic or sub-chronic doses the heavy metals and PFAS become very hazardous materials, and so it is important that contaminants from solar panels, batteries, inverters, and transformers do not enter the environment (air, soils and water).

In New Zealand the Resource Management Act was passed into law in 1991 to specifically prevent human activities and development of amenities impacting natural assets like soils, air, and water. More specifically within this Act are provisions that prevent contaminants from industry not only affecting natural assets, but the flora, fauna, and health of organisms within different ecosystems.

Because New Zealand is reliant on primary production for trade (81.4% of exports still come off the land), the New Zealand government introduced the National Policy Statement on Highly Productive Land (NPS-HPL) under section 52(2) of the Resource Management Act during 2022. Theoretically this should protect good farmland for agriculture and horticulture, but increasingly that intent is compromised by use of the green belt around towns for housing development, and the use of productive land for utility-scale solar photovoltaic (USSP) facilities. This lack of due diligence by councils at protecting productive lands ultimately results in lost export earnings and New Zealand running bigger and bigger current account deficits each year.

The National Policy Statement for Freshwater Management (NPS-FM) was introduced under section 52(2) of the Resource Management Act in 2020, in a hope of preventing further desecration of rivers and lakes as happened during 2000-2020 following poor local government administration of the RMA. The NPS-FM contains specific directions on water management to prevent contaminants from farms being leached into both surface-water and groundwater. However, existing eutrophication of most lowland rivers and all lowland lakes in the Selwyn District because of poor council management of natural assets, has the potential to be exacerbated by added heavy metals and per-and poly-fluoroalkyl (PFAS) from solar farms.

Selwyn District Council and Environment Canterbury are signatories with Ngai Tahu within a co-governance agreement for Te Waihora. That co-governance agreement specifically refers to the protection of kai (food from the lake for the **'kaitiakitanga'** or guardians of the lake) and improvements to water quality. In deference to local treaty partnerships between Maori and the Council, a solar farm is being constructed on the banks of a waterway flowing into the lake; a guaranteed mechanism for further polluting the lake with heavy metal and PFAS contaminants from a solar farm.

Despite the clear directions within RMA legislation and Local Government Act 2002, councils continue to make major and sometimes catastrophic change to the environment by exempting both the public and Crown Research Institutes from their decision-making through "limited notifications" of "discretionary activities". In this study the impacts of solar panels on soils gazetted as LUC2 and LUC3 lands at Brookside (i.e., "highly productive lands") were assessed by taking soil samples from under solar panels and comparing them with 'control' soils some 40-90m away. In addition to contaminants in soils, contaminants in vegetation were also measured. The implication of these contaminants on soil changes and soil compaction are discussed, the implication of increased run-off of floodwaters containing contaminants are discussed, the effects on terrestrial vertebrates are discussed, and results from this study are compared with published research done elsewhere.

Methods

1. *Panels*

A small array of solar panels was established at the property of Michael Dalley at Brookside during 2014. These were arranged on 12 rows of tables that was each fitted with between 4—20 polycrystalline solar panels per table (type = Kyocera KD215GH-2PU panel). After 9 years exposed to the weather the panels superficially appeared to be in good condition, but there were overt signs that leachates from panels were affecting plant growth. Some vegetation beneath the panels was stunted and the leaves of some grasses were bronzed. Furthermore, it was self-evident that the composition of plant communities under panels had changed.

2. Soils

Soils were independently sampled from beneath panels by a soil technician from Ravensdown Ltd. (Kate Higgins) using a probe that took cores to a depth of 15cm. A total of 6 'test' core samples were taken from under panels and compared to 6 'control' soil samples taken approximately 40 metres distant from panels. Other than contaminants from panels, the test and control soils were originally very much the same. The probes of soil were placed in a chilli bin and maintained at low temperature while being transported to Analytical Research Laboratories, Napier. At the laboratory soils were maintained at <10^{0}C prior to analysis. During analysis all soils were air dried at 38 ^{0}C and ground to pass through a 2mm screen. The 'test' and 'control' soils were then separately blended into two homogenous samples. The list of established analytical methodologies used on soil samples is summarized in appendix 1, with lengthy protocols for each test available from ARL Labs or the authors for anyone wanting a detailed description of laboratory methodologies.

Differences between "test" and "control" soils were measured as:

- changed concentration of heavy metals in 'test' compared to 'control' soils,
- differences in NPK (nitrogen, phosphorous, and potassium),
- differences in nitrate-nitrogen,
- differences in total organic carbon and total nitrogen, and
- differences in soil pH.

2) Contaminants in ryegrass

A 'test' sample of early-summer ryegrass with developing seedheads was taken from under panels and levels of macronutrients, trace elements, and ancillary heavy metals in that grass compared by Hill laboratories (Hamilton) with 'control' ryegrass harvested 40-m from panels.

3) Changes in microorganisms in soil

Soil probes (*n*=10) were taken from each of 'test' (contaminated) soils and 'control' soils (50-100m from panels). In addition, the root systems of 2 clover plants were recovered from near solar panels (viz. 'test' plants) and the root systems of 2 clover plants were recovered from soils 50-100m away from panels ('control' plants). Each of these samples was placed in an individually-labelled plastic bag and couriered to 'Soil Foodweb NZ' for counts of microorganisms (bacteria, fungi, protozoa, and mycorrhizae per gram of soil (µg/g or cfu/g) or counts of mycorrhizae on clover roots (% of root colonized).

4) Changes in earthworm abundance

Plugs of soil (n=10) to a depth of 15cm were dug up from under solar panels and weighed on an electronic balance before being manually crushed, and where practicable screened on a soil sieve to remove earthworms from soils. The count of worms was recorded alongside the soil weight to estimate worms per kilogram of 'test' soil.

The process was repeated in 'control' soils 50-100m distant from solar panels. The 10 counts of earthworms per kilogram of soil in 'test' and 10 counts in 'control' soils were then compared by an unpaired t-test to establish whether there was any statistical difference in worm abundance.

5) Pasture composition

An examination of the site showed distinct differences in the pasture composition of 'test' soils adjacent to solar panels compared to pasture on normal 'control' soils. The entire pasture was a mix of 'Nui' ryegrass and 'Huia' white clover established before the solar farm was constructed during 2014. The two species in pasture are at opposite ends of the spectrum for susceptibility to heavy metals; Nui ryegrass will bioaccumulate heavy metals at 'normal' pH (Gray & McLaren 2005), but heavy metals in soils will kill clovers (Sotiriou *et al.* 2023). For this reason, white clover was used as an indicator species for the presence of heavy metals and any potential change to soil microorganisms within soils (Zhang *et al.* 2022).

A circular hoop with an inner circumference of 3.54m and diameter of 1.13m was used to record the number of clover plants per square metre of pasture. Transects were randomly located through the site using 120m of twine strung between posts at opposite ends of the solar enclosure. Along the transect a splash of red paint had been applied to twine at 4m-intervals. At each 4m point the distance from the centre of the vegetation hoop placed on the ground to the nearest solar panel was measured with a fibre tape. In this way pasture was searched semi-randomly for clover plants in relation to the distance from solar panels. The number of clover plants in the hoop was counted.

The abundance of clover plants in pasture was then correlated with the distance from the source of leachates by regression analysis. Data was tested by ANOVA and multiple-range tests performed on clover abundance using distance from panels as a treatment factor.

6) Legislation

The implications of this study in regard to the RMA 1991, the national policy statement on highly productive lands (NPS – HPL), the national policy statement on freshwater management (NPS – FM), and treaty partnership between Selwyn District Council and Maori for co-governance of Lake Te Waihora are discussed.

Results

Soils

Plant nutrients found in soils fall into three classes as:

- <u>macronutrients</u>: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S), carbon (C) magnesium (Mg), hydrogen (H), oxygen (O): or,
- <u>micronutrients or trace minerals</u>: iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), Nickel (Ni), selenium (Se): or,
- <u>ancillary heavy metals</u>: sodium (Na), lead (Pb), aluminium (Al), cadmium (Cd), silver (Ag), mercury (Hg), arsenic (As) chromium (Cr), lithium (Li), strontium (Sr), titanium (Ti), indium (In), tin (Sn), etc.

In general, an elevation of macronutrients is tolerated by most plants, but when 'trace' elements and ancillary heavy metals exceed a threshold determined by soil pH, soil structure, and soil moisture then they become toxic to plants. Once trace elements and ancillary heavy metals reach a critical threshold, they become toxic enough to kill 50% of soil microorganisms (referred to as the EC_{50}). Unfortunately, most of the trace elements and all the ancillary heavy metals listed above are in different types of solar technology, so leachates not only affect soils, but they also eventually affect plant growth.

The percentage increase or decrease of bioavailable <u>macronutrients</u> in soils under solar panels are shown below (Table 1). There has been a substantial increase in nitrogen, nitrate-nitrogen and sulphates leached from panels. In comparison, bioavailable phosphates and potassium have declined substantially.

Table 1. **The percentage increase or decrease in macro-nutrients in soils following a 9.5-year period under solar panels.**

Unit	N nitrogen	$N\text{-}NO_3$ Nitrate-nitrogen	P phosphate	K potassium	Ca calcium	S or SO_4^-	Mg magnesium	carbon-nitrogen ratio
Change (%)	+38%	+40%	-34%	-63%	0%	+333%	+14%	-11.2
mg/kg[a] or QTU[b]	20.2[a]	21.7[a]	37[a]	12[b]	14[b]	26[a]	65[b]	9

QTU = quick test unit (kg/ha)

The percentage increase in 'trace elements' leached into soils from solar panels is shown in Table 2. The largest amounts of added trace elements were Fe, Mn, Na, B, and Cu. The rise in Fe was massive at 826 mg per kg of soil.

Table 2. **The percentage increase in trace elements added to soils during a 9-year period of leachates from solar panels.**

Unit	Fe	Na	Cu	Co	Mn	Zn	Ni	B
Change	+72%	+33%	+22%	+13%	+14%	+4%	+4%	+17%
mg/kg	2,040	8	4.4	1.7	274	12.7	10.1	2.1

The increase in ancillary heavy metals from solar panels added to soils is shown in Table 3. The largest increases in ancillary heavy metals added to soils were aluminium (Al), lead (Pb), and arsenic. The rise in total aluminium in soil was massive at 800 mg per kg of soil.

Table 3. **The percentage increase in heavy metals leached onto soils by solar panels.**

Unit	As arsenic	Cd cadmium	Cr chromium	Pb Lead	Al[a] Aluminium	Hg Mercury
Change (%)	+27%	+29%	+6%	+22%	+5.3% or	n/a
mg/kg	5.2	0.22	19.7	20	added 800 m/k	<0.12

[a] *Toxic to legumes above 3mg/kg, highly toxic @3-10 mg/kg, very toxic to plants >10 mg/kg*

All these leachates (Tables 1, 2, 3) either aid or impede plant growth depending on the concentration in soils, the type of plant growing in soils, soil pH, and soil moisture.
In addition to these measured changes, the soil pH declined from 6.6 to 5.9, bioavailable potassium declined from 32 to 12 kg/ha and soluble phosphorous/phosphate declined from 56 to 37 ug/ml (both factors caused by iron and aluminium added to soils). Total organic carbon was unchanged suggesting that at this early stage in the life cycle of panels, earthworms were still active in soils.

Contaminants in ryegrass

Ryegrass was actively growing because of added nitrogen leached from solar panels, and this ryegrass bioaccumulated heavy metal contaminants from soil. Although bioactive potassium (K) and phosphates (P) were reduced by increased occlusion and absorption/adsorption (viz. soil properties changed by added iron and aluminium) this made little difference to the composition of the ryegrass plant (Table 5). The only significant change was an increase in sulphates that had also increased in soil.

Table 5. Macro-nutrients measured in ryegrass under solar panels

Unit	N nitrogen	P phosphate	K potassium	Ca Calcium	S or SO_4^-	Mg magnesium
Change (%)	+7%	-12%	-0%	0%	+18%	+0%

mg/kg[a] or % of plant[b]	1.5[b]	0.23[b]	1.5[b]	14[b]	0.2[b]	0.14[b]

The increase in trace elements in ryegrass is shown in Table 5. The biggest increases of trace elements in grasses were from leached pyrites (Fe), leached manganese (Mn), leached copper (Cu), leached boron (B) from in borosilicate glass, and leached anti-reflective coatings (e.g., Na).

Table 5. The percentage increase in trace elements in ryegrass plants under solar panels.

Unit	Fe	Na	Cu	Mn	Zn	B
Increase (%)	+42%	+33%	+14%	+14%	+0%	+40%
mg/kg	98	8	8	274	20	7
WHO (MAL)	150	n.s.	10	44.6	0.6	n.s.

The increase in heavy metals in ryegrass is shown in Table 6. The largest increases were aluminium and lead (Pb).

Table 6. The percentage increase in ancillary heavy metals in ryegrass near solar panels.

Unit	Al Aluminium	Pb Lead	Cd* Cadmium	As* Arsenic	Cr* Chromium
Increase (%)	78%	20%	unk	unk	unk
mg/kg	41	6	<0.04	<0.1	<0.2
WHO (MAL)	5	2	0.03	1	1.3

- the limit of detection on tests was not sensitive enough to monitor **increase.**

Aluminium in plants has increased as a result of an increase in leachates from solar panels. Although it is an amphoteric substance that dissolves and subsequently affects soils and plants at low or high pH (Fig. 1), the subtle change in pH during this study (pH 6.6 → pH 5.9) will make little difference to its availability in soils. However, as pH falls further (i.e., pH <5.5) then it will become more labile and it will both a) increase in bioavailability and b) bioaccumulate in plants because of ongoing leaching of aluminium from panels. At that stage it will have serious consequences for the productivity of ryegrass and clover growing on the land (*see* discussion).

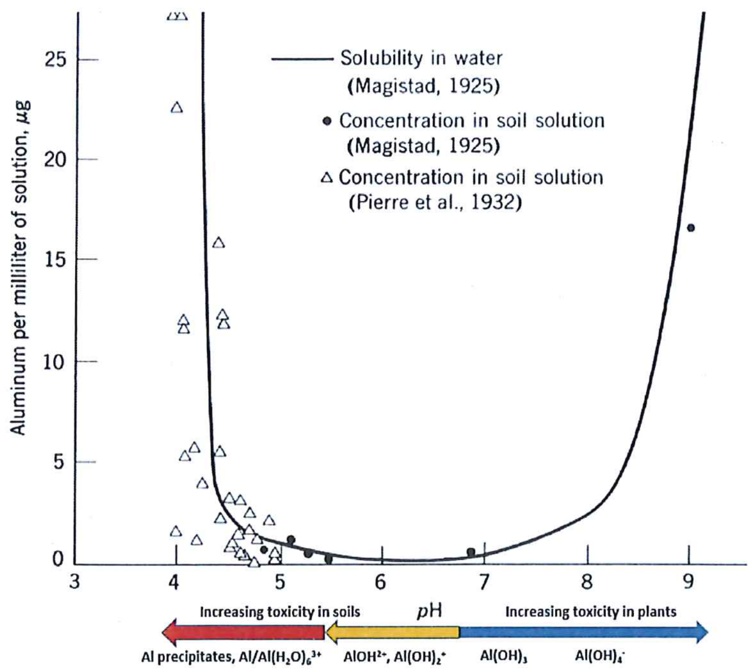


Figure 1. **The solubility of aluminium at different pH-values in water, which is then adsorbed to roots as Al^{3+}, $AlOH^{2+}$, $Al(OH)_2^+$ when pH is ≤6.5, or absorbed as $Al(OH)_3$ or $Al(OH)_4$ when pH is >6.5.**

Changes in microorganisms in soil

The overall results show a substantial decline of microorganisms in soil as heavy metals have been leached from panels (Table 7). The fungal levels in soils were generally low because permanent pasture had not had significant organic matter added for several years. Total bacteria in 'control' soils were 'normal' and were less affected by contaminants than fungi. Soil amoeba and ciliates (i.e., protozoa) were decimated by added heavy metals.

Table 7. **Measured microorganisms in 'test' soils below solar panels and 'control' soils in an adjoining paddock.**

Type of microorganism	'Normal' range	'Test' soils	'Control' soils	Decline
Fungi				
Total fungi (μg/g)	>300	140.4	297.5	52.8%
Active fungi (μg/g)	>30	4.0	8.3	52.0%
Mycorrhizal fungi (% clover root colonized)	50 -70	22	54	59.3%
Bacteria				
Total bacteria (μg/g)	>300	377.8	453.6	16.7%
Active bacteria (μg/g)	>30	11.8	13.7	14.0%
Protozoa				
Amoeba (cfu/g)	>10,000	175	1901	90.2%
Ciliates (cfu/g)	<7,000	579	8084	92.8%
Flagellates (cfu/g)	>10,000	579411	647103	10.5%

Changes in earthworm abundance

Earthworms in soils were generally small in size and low in abundance. Because the soils under solar panels were compacted with many hard clods it took some time to break it down into small particulates of a size that could not harbour an earthworm. To do this these soils were spread onto a breadboard and then systematically crushed. On average, around 1.8 kg of soil down to a depth of 15cm was systematically searched in each sample until the observer was confident all worms were found. Results showed worms were not uniformly distributed throughout either 'test' or 'control' soils. More importantly there were significant differences ($t=4.1$, $P<0.01$) in the numbers of worms in 'test' compared to 'control' soils, with numbers down on average by 64% in 'test' soils that contained contaminants compared to the 'control' soils on open farmland.

Table 8. **Numbers of worms in 'test' soils under panels, and 'control' soils.**

Plot	Worms per kg of 'test' soils	Worms per kg of 'control' soils
1	1.0	3.8
2	1.4	2.2
3	1.4	3.5
4	1.2	1.9
5	0.6	5.7
6	0.0	3.2
7	1.2	3.2
8	1.6	1.7
9	1.5	5.3

10	1.8	1.3
Mean ±std. dev.	1.2 ±0.5	3.2 ±1.5

Pasture composition

If all contaminants were dropped onto soils from a common source and were subsequently dispersed by physical forces, then amounts at a set distance from that source would follow an 'inverse square law'. Conversely, the diminishing effects of contaminants on clover should be measured as the square of the distance from the source of contamination. Therefore, as expected, regression analysis showed clover abundance in pasture fitted a power function (r^2=0.96) almost perfectly, because growth factors for clover plants are directly associated with the diminishing effects of soil contaminants as vegetation plots were placed further from solar panels (Fig. 2). Although we never had the time or resources to harvest and measure the biomass of ryegrass, the trend was the opposite of that seen for clover. The large amounts of nitrogen coming off panels promoted ryegrass growth close to panels, and the biomass of ryegrass declined the further from panels vegetation plots were located. This effect was misinterpreted by an agronomist inspecting solar panels on the Ward farm as a changed "micro-climate" between panels that he believed promoted vegetative growth. It is in fact simply a result of added nitrogen and nitrates to soil.

Although the paddock where panels were located was reasonably flat, there were small humps, slight hollows, and gaps between some solar panels; so, predictably contaminants were not spread uniformly. Despite the variance in data created by these subtle effects, the differences between the 'distance classes' shown in figure 2 were highly significant ($F_{4,126}$=16.3, P<0.01) with a Duncan's multiple range test showing significant differences (P<0.05) between treatment groups.

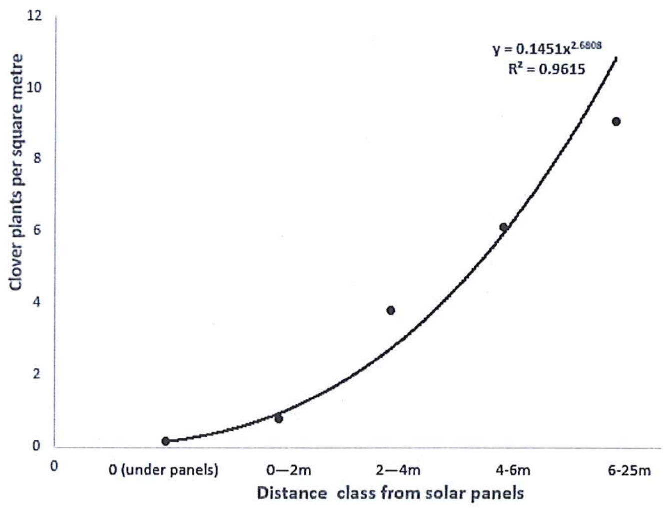


Figure 2. **Trends in the abundance of clovers in pasture in relation to the proximity of plants to contaminants leached from solar panels.**

Contaminants washed from the solar farm

In contrast to results shown above on a flat paddock, in a contoured paddock where there are gullies that drain surface waters away from the solar farm, then heavy metals will be dispersed in floodwaters flowing along those gullies to create a stream of effluent contaminants into neighbouring properties, and eventually into adjoining streams (*see* Photo 1).

N2_20170722_163951 - Buckleys Road and Brookside and Irwell Road (south-west)

Photo 1. **Run-off of floodwaters that will contain heavy metal and PFAS contaminants if a solar farm is located at Brookside.**

Discussion

Solar farms require large land areas (c. 1.5 - 3ha per Mw of electricity; Onga *et al.* 2013) to generate electricity. The land under USSP-facilities is changed by solar panels, batteries, inverters, transformers, and other infrastructure placed above ground. A multitude of studies have demonstrated different types of leachates occur under different types of solar panels (e.g., Lu *et al.* 2022), and they invariably change plant communities growing in soils contaminated with leachates (e.g., Bai *et al.* 2022). In a seminal study in Italy, it was found the type of solar panel used at that site reduced total organic carbon in soils by 61% and soil nitrogen by 50% because soil contaminants had changed the abundance of soil invertebrates and types of soil microorganisms (Moscatelli *et al.* 2022). Further research in Wales has demonstrated that siting utility scale solar panels on farmland reduces land productivity through a marked increase in soil compaction, and an inability to routinely undertake soil cultivation and pasture renewal amidst tables of solar panels (ADAS 2023). Other dimensions of land productivity affected by panels have been documented as an inability of soils containing high leachates (e.g., Pb) to germinate seed (Choi *et al.* 2020), and an inability of some types of plant to grow in 'Oxisol' soils (viz. soils with a low pH) that contain Zn, Cu, Ni, Ga, Pb, In, Cr and Al leachates from thin-film solar panels (e.g., Su et *al.* 2019). All these studies show solar technologies at USSP facilities change the productivity of land in their own unique way, in deference to the provisions of the NPS—HPL issued by the New Zealand government.

There are a multitude of different materials used in technologies to manufacture solar panels, within the framing for tables, within inverters, within transformers, within cabling, within circuit boards, and within batteries. The main ones detected as important leachates during ongoing research are shown in table 9 in comparison with brodifacoum (as a toxic rodenticide). We can immediately see from this table that most materials used to make solar technologies are very hazardous when released into the environment. In the model 'Risks=Hazards x Exposure', if "hazards" are high, then "exposure" must be low. Unfortunately, the research reported here demonstrates exposure is not low.

Table 9. The half-lives, health, and environmental risks of materials used in solar technologies by HSNO classification.

Chemical	Metal half-life Liver (d)	Aquatic toxicity 9.1	Soil toxicity 9.2	Terrest. Vert. 9.3	Oral toxic 6.1	Mutagen 6.6	Carcinogen 6.7	Reproductive toxicity 6.8	Target Organs 6.9
Brodifacoum	114.6	9.1D	n/t		6.1E				6.9B
Aluminium	150 in liver; 7years brain	9.1A	9.2B		6.1E				6.9B
Lead	36 blood 130 liver 2 years brain	9.1A 9.1B	9.2B	9.3A	6.1C	6.6B	6.7B	6.8A	6.9A
Silica		9.1B		9.3C					6.9A
Cadmium	4 -19 yrs	9.1B			6.1C		6.7A	6.8B	6.9A
copper	21 d 435 d brain	9.1A	9.2D	9.3B	6.1B	6.6A			6.9B
Nickel	35 d	9.1B		9.3B	6.1C		6.7A		
Boron	1.5 d	9.1B	9.2D	9.3C	6.1E			6.8B	6.9A
Zinc	245 d	9.1A		9.3C	6.1D				6.9B
Silver	50d	9.1A	9.2B	9.3A	6.1C			6.8B	6.9A
Arsenic	10 hrs	9.1A	9.2B	9.3B	6.1C		6.7A		6.9A
Chromium	9 d	9.1A	9.2B	9.3B	6.1A	6.6A	6.7A	6.8A	6.9A
Selenium	150d	9.1C	9.2C		6.6B	6.6B			6.9B
Lithium	1-2d	9.1D	9.2D		6.1D				
Strontium	50.5 d	9.1C	9.2D		6.1D				
Titanium	12.7 d	9.1B			6.1E		6.7B	6.8B	
PFAS	5.5 – 8.5 yrs	9.1A 9.1B	9.2C	9.3B	6.1C			6.8A	6.9B

The risks associated with these leachates are updated every 2 years within the ATSDR (Agency for Toxic Substances and Disease Registry) for impacts on human health (i.e., hazard x exposure). Within this list arsenic is ranked as hazard No. 1, then No. 2 (lead), No. 3 (mercury), No. 5 (polychlorinated biphenyls), No. 7 (cadmium), No. 9 (polycyclic aromatic compounds), No. 17 (chromium), No.57 (nickel), No. 74 (zinc), No. 104 (thorium), No. 120 (copper), and No. 127 (strontium). Just below that place on the list is manganese, fluoranthene, selenium, a range of per- and poly-fluoroalkyls, aluminium and silver. Essentially, at solar farms many substances that present a significant risk to human health and the health of ecosystems are continuously leached into the environment.

Within New Zealand the Ministry for Environment (MFE) has similarly assessed heavy metals in soils and listed the most serious as arsenic, lead, boron, cadmium, chromium, copper, mercury (MFE 2011, Cavanagh *et al.* 2023). Once again, these are substances leached from solar technologies during ongoing research.

A quick perusal of the table 9 above shows all components of solar technologies present serious risks in aquatic ecosystems (HSNO classifications are mainly 9.1A or 9.1B), and most are toxic to soil organisms (HSNO classifications are mainly 9.2B). Also of note are oral toxicities, and effects on

target organs. The oral toxicities are not acute (i.e., hazard class 6.1A or 6.1B where a material ingested as a single dose may be lethal within 24-48 hours) but have classifications that range from 6.1C to 6.1E (i.e., they only become toxic when consumed in small, divided amounts as a chronic or sub-chronic poison). The potent rat poison (brodifacoum) is listed in the same way (6.1E), but it will readily kill all rats when ingested as a chronic poison over 3 days. Just like brodifacoum in the rat poison, what makes these materials toxic is they have a long half-life and readily bind to tissue where blood is filtered (viz. the liver, kidney, placenta, cardio-respiratory system, and brain), and they bioaccumulate over many months until they have serious effects on target organs (HSNO classifications are mainly 6.9A and 6.9B). Birds or rodents feeding around solar farms that eventually find themselves feeding on contaminated vegetation, contaminated berries, contaminated seeds, contaminated earthworms, or contaminated Porina caterpillars will progressively bioaccumulate toxic amounts of heavy metals that affect breeding, and inhumanely debilitate the health of the bird (HSNO=9.3A or 9.3B). We also get tertiary poisoning because raptors (owls, hawks, falcons) feed on sub-lethally poisoned mice, rats, and small birds, and these raptors then bioaccumulate toxic levels of heavy metals and PFAS compounds (HSNO=9.3A or 9.3B). Offshore, there are serious concerns about heavy metals and PFAS substances in kestrels, owls, hawks, and falcon (e.g., Scheuhammer 1987, Monclus *et al.* 2020). For this reason, heavy metals and PFAS have a HSNO classification of 9.3A or 9.3B for terrestrial vertebrates.
In aquatic environments a similar phenomenon is observed with aquatic plants (e.g., plankton, algae, watercress) bioaccumulating heavy metals and PFAS, invertebrates ingest heavy metals or PFAS that are then eaten by small fish, that are then eaten by large fish (Ali *et al.* 2019). At each trophic level the metals and PFAS bioaccumulate until they eventually become lethal. For humans feeding on contaminated fish this creates increased risks of cancer, liver disease, nephritis, and neurological disorders (Panda *et al.* 2023). In the USA and China freshwater fish are now so contaminated with PFAS and heavy metals that many authorities recommend people not consume them (e.g., Barbos *et al.* 2022, Ai *et al.* 2022).

The research outlined in this study demonstrates a proposed solar farm on heavy silt loam soils at Brookside will result in compacted soils because of high levels of added iron and aluminium that form clods, this will result in poor water dispersion, and will increase run-off of flood waters containing contaminants. Leachates from solar panels, leachates from batteries, and leachates from other ancillary equipment not only change soils, but the composition of plant communities growing on those contaminated soils. If widescale use was made of the panels currently located at Buckleys Road, then at the very least in the long-term the iron and aluminium released from panels would exacerbate compaction of topsoil (Mazurana *et al.* 2017, ADAS 2023), result in the development of an iron pan above subsoil (Cunningham *et al.* 2001), the heavy metals deposited on soils would collectively impact the abundance of soil micro-organisms (Zhang *et al.* 2023, Jarosławiecka *et al.* 2022), and the panels would change the composition of plant communities over extensive areas of pasture. The outcomes of this after 9.5 years are already apparent with the loss of clovers growing in and around solar panels at Buckleys Road.

Varieties of ryegrass (e.g., 'Nui') that are moderately tolerant of heavy metals compared to newer varieties like 'Expo' (Parra-Almuna *et al.* 2018) grow well between panels because of increased nitrogen and nitrates leached from panels. However, if pH drops further to a value around 5 then aluminium (Al) toxicity and low phosphorus (P) and potassium (K) availability will also present as a serious problem for vegetative production of Nui ryegrass (Parra-Almuna *et al.* 2018). This actively growing grass currently bioaccumulates contaminants from panels which are then eaten by sheep, which in turn bioaccumulate "forever chemicals" in the livers, kidneys, cardio-pulmonary tissue, and the brain which impacts animal health and animal welfare. These heavy metals may also change blood parameters in sheep like RBC (red blood cell) count, WBC (white blood cell), PLT (platelet) counts, and immune responses to pathogens (Kovacik *et al.* 2017, Sani *et al.* 2023, Medani *et al.* 2011).

Unbelievably, proponents of solar farms have become indoctrinated with a belief that this is all "clean and green", because that is a message that has been repeated to them over-and-over again.

a) Impacts on soils

In this study the assay of contaminants in soils measured just one point in a typical decay curve of materials being leached from solar technologies (Fig. 3). At this early stage, the outer antireflective coatings (ARC) containing sodium nitride (Na_3N), silicon nitride (Si_3N_4) and polyfluoroalkyl substances (PFAS) have in part been washed off panels; and pyrites (FeS_2) has been leached from the layer under the ARC layer. Through hydrolysis pyrites is transformed to soluble iron (Fe^{2+}) and sulphates (SO_4^-); while those heavy metals in the core of a solar panel (e.g., Cu, Pb, Cd, As) are already slightly elevated in soils to the stage where you wonder where levels will be in another 10 years.

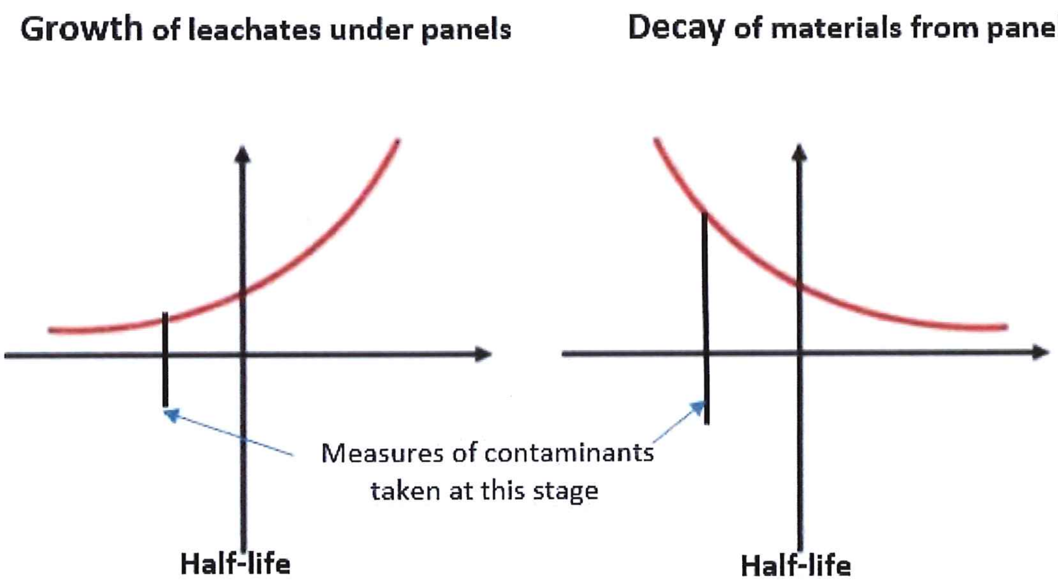


Figure 3. **Typical growth curves for leachates in soils, and decay curves for loss of materials during the weathering of panels.**

These core elements will increasingly be deposited on soils and accumulate as panels degrade. The NPK of soils has changed with N (nitrogen) elevated as a leachate from panels, nitrate-nitrogen is at concentrations typically found on a dairy farm, and both P and K (phosphates and potassium) are lowered because clods containing iron have increased occlusion and adsorption/absorption of these critical nutrients (*see* Fig. 4 below). The increased nitrogen has increased the growth of ryegrass between panels. The acidity of soil has increased because of released H^+ in the reaction $FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 4H^+ + 2SO_4^{2-}$ and the reactions facilitating hydrolysis of aluminium, which in time will lower pH further and make heavy metals such as aluminium more toxic in soil. Furthermore, this one assay did not include some elements (e.g., In, Sn, Ag) known to be released during the latter stages of degradation of polycrystalline solar panels. During advanced breakdown of panels Sharma *et al.* (2021) recorded lead (Pb) leachates from badly degraded polycrystalline panels at dangerously high concentrations of 9.3 mg/L, and 6.7 mg/L in the TCLP, and SPLP tests.

Because this assay of soils is from panels in the early stages of degradation, it is unknown where leachates will be 10 or 20-years from now.

The literature suggests contaminants leached onto soils are released progressively during different chronological periods as the laminates in solar panels progressively weather and degrade; so, it is a bit like peeling layers off an onion year after year until most leachates are eventually released into the environment. The schematic portrayal of this process above (Fig. 3), does not show episodes of leaching that follow catastrophic events (e.g., extremes of UV light, hail stones "pitting" panels, freeze-thaw following snow, wind damage that twists and breaks panels, and of course fire that instantaneously liberates most compounds for rapid leaching onto soils).

Initially, during normal weathering the outer anti-reflective coatings (ARC) on the surface of a panel are lost. ARCs are multi-purpose and a) utilize superhydrophobic properties to repel both water and dust particles, b) they protect against harmful ultraviolet (UV) radiation, and c) they optimize uptake of energy from the sun. There is no established form of ARC that is universally used on all panels, but they are comprised mainly of SiO_2. MgF_2, TiO_2, Si_3N_4, Na_3N, ZrO_2, AlO_3, and PFAS like polymethyl methacrylate (Sarkin *et al.* 2020). All of these substances are toxic to aquatic organisms, and some are toxic to soil organisms. Some materials like silicon nanoparticles that are washed off panels will not show up in soil tests, but they have finely ground silica particles that get into the gills of fish where they are lethal (Book *et al.* 2019; HSNO=9.1B).

To manufacture pyrite crystals for solar panels, sulfurization of the raw product happens at high temperatures and pure FeS_2 crystals are then layered on an indium–tin glass which leaves measurable amounts of In and Sn throughout the matrix as conductors (Lu *et al.* 2021). These contaminants were not tested during this soil analysis. The important leachates at this stage are iron and aluminium. Iron (Fe^{2+}) becomes increasingly toxic in well-drained loams at concentrations exceeding 1000 mg/kg (depending on soil type). However, as moisture is progressively increased and soils become saturated (e.g., in a rice paddy), then Fe^{2+} becomes toxic at concentrations as low as 200ppm. In these saturated soils containing iron it is essential to add potassium as fertilizer if it is to grow rice, because potassium is occluded by the presence of iron and aluminium. Added water-soluble iron washes through sandy soils, but in heavy loams such as those found at Brookside it accumulates. This same adage applies to other types of heavy metals (Al, Mn, Cu, Zn, Pb, Cd, As, etc) applied to loams. Heavy metals not leached out of soils become especially problematical in saturated soils. Percolation of Fe down through soils with high rainfall results in an iron pan where there is a clay substrate (Cunningham *et al.* 2001), a process that happens in as little as 3 decades. Soil flocculation in the presence of Fe results in the formation of hard clods and compacted soils (Mazurana *et al.* 2017). Within these clods occlusion of potassium and absorption/adsorption of phosphate reduces the bioavailability of potassium and phosphates to plants (Fig. 4). In rice paddies with saturated soils iron is always a problem, so potassium (K) that is essential to grow rice is routinely added to increase crop yields (Sahu *et al.* 1992, Sahu *et al.* 2001).

Root exposure to high sodium concentrations causes wilted foliage and stunted plant growth. This is because excessive salts in soil impede the uptake of water by plants and causes plant tissues to become dry and discoloured. The effects of high sodium, high iron, and high aluminium in soils can be seen under panels where vegetation growth is stunted.

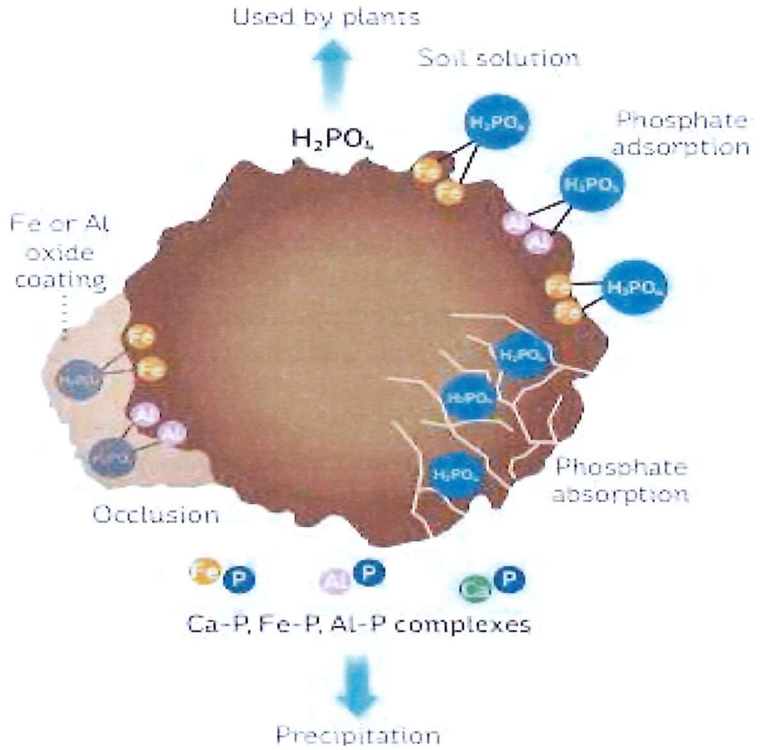


Figure 4. Clod formation in the presence of iron (Fe), with iron/aluminium occlusion of potassium and phosphates, and absorption/adsorption of phosphates.

Soil organisms

There are many effects of heavy metals on soil microorganisms which cannot all be described in detail in just a few sentences. One of the most toxic is copper which is used as a fungicide in orchards where it presents as a problem for soil microorganisms (Keiblinger *et al.* 2018). A study found that the EC_{50} for Cu varied from 9.2 to 187 mg/kg for different types of fungal microorganisms in different types of soil; and it resulted in radical Cu-induced changes to the colony composition of soil microorganisms (Keiblinger *et al.* 2018). Ongoing leaching of copper into Brookside soils may similarly cause changes in soil microorganisms. At this stage it is not high enough to be of concern. Aluminium toxicity to soil microorganisms is also a factor because of its high concentrations in soils compared to some other leached metals (viz. in the model 'Risk=Hazards x Exposure', exposure to aluminium by microorganisms is very high). When pH is <5 and Al^{3+} becomes labile, this then devastates both rhizobium in soil and fungi (Niu *et al.* 2020). As aluminium- sensitive fungi in soils are reduced, aluminium-tolerant fungi (*Penicillium, Cladosporium, and Talaromyces*) increase, and this changes the bioavailability of plant nutrients (Shi *et al.* 2020). Other heavy metals leached onto soils also change communities of microbes in soil (Jarosławiecka *et al.* 2022).

In this study, a primary soil contaminant was Fe^{2+} that causes significant changes to soil bacteria. The aerobic *Pseudomonas, Sphingomonas, Nictobacter, Escheria* and *Acidovorax* are significantly inhibited by Fe^{2+} which reduces the amount of oxygen in soils; this then increases anaerobic and chemoautotrophic bacteria like *Alicylobacillus, Desulfosporosinus*, and *Nitrosovibrio* that increase CO_2 in soils, increase the release of methane, and change sulphates to sulphides (Zhang *et al.* 2022).

During this study, we did not have the resources to identify types of microorganisms. However, the soil contaminants leached from panels have impacted soil by reducing total fungi by 53%, soil mycorrhizae (nitrogen-fixing fungi on clover roots) by 59%, soil amoeba was reduced by 91%, ciliates by 93%, and overall bacteria by 17%. So, in this study soil fungi and protozoa were more affected than soil bacteria.

The cultivation and cycling of carbon in soils is facilitated naturally by earthworms. However, all the vectors listed above impede this process; poor water dispersion and contaminants make the habitat undesirable for worms. Toxic metals like cadmium, lead, arsenic, chromium, etc at low concentrations bioaccumulate and affect worm health. Some metals get encapsulated in worm casts; but at high concentrations heavy metals progressively kill worm populations and change the dynamics of invertebrates and soil fertility (Yadav *et al.* 2023). In this study worm populations in contaminated soils were only 36% as abundant as worms in 'control' soils. Long-term this may impact total organic carbon in soils.

There is not a lot that is positive about the build-up of heavy metals in soils.

Impacts of heavy metals on plant communities

Cyclic effects

(Ryegrass (*Lolium perenne* var. Nui) is a species that will grow in soils contaminated with heavy metals and PFAS due to its ability of rapidly producing substantial biomass when nitrates are added. The biomass of plant matter that grows with high levels of nitrogen in soils then bioaccumulates large amounts of heavy metals (Arienzo *et al.* 2004; Ke *et al.* 2021; Zayed and Terry, 2003), Nie *et al.* 2023). Therefore, certain varieties of ryegrass (e.g., Nui) readily bioaccumulate heavy metals found in soils (Gray & McLaren 2005). Other varieties (e.g., Expo) are quite sensitive to aluminium and growth of this plant is significantly suppressed (Parra-Alumna *et al.* 2018). In a single study by Gray (2005) heavy metals from contaminated soils were measured in long-established ryegrass pasture at 53 mg/kg (Zn), 1.1 mg/kg (Ni), 2.6 mg/kg (Cu), 334 mg/kg (Mn), and 52.2 mg/kg (Fe). In this study it was surprising that plants contained as many heavy metals as recorded. The tall ryegrass at the time of the study contained high concentrations of Fe (98 mg/kg), Mn (274 mg/kg), Al (41 mg/kg); while Cu, Na, B, and Pb at this early stage of leaching from the core were all significantly elevated as leachates off solar panels. Although cadmium, chromium, and arsenic were elevated in soils, at this stage they were below the LOD (level of detection) in grass. Sheep eating this tall ryegrass will undoubtedly bioaccumulate a percentage of PFAS and heavy metals in livers, kidneys, brains, pulmonary tissue, and the placentas of pregnant ewes that will impact animal health and the health of their offspring. The remainder that is not digested, absorbed, or bioaccumulated in tissue will be excreted back onto the surface of ground and taken into soils by earthworms and/or washed into the soil surface. By the end of winter concentrations of contaminants in soil will be substantially higher than what was recorded during this study during early summer. At this stage, the only discernible impacts on ryegrass were stunted growth and bronzed foliage under panels where leached contaminants were highest. These patches of severely affected vegetation are likely to increase in size with the passage of time.

Clovers are very susceptible to heavy metals that change healthy soils. The clover plant is impacted in three ways; a) Arbuscular mycorrhizal fungi on the roots of clover that aid in the uptake of phosphates are killed by Fe^{2+} Al, and other heavy metals in soil; b) the presence of iron (Fe^{2+}) and Al at high concentrations in soil reduces bioavailable phosphates by 52%; and, c) the presence of high Fe^{2+} in soils lowers bioavailable potassium by 63% to only 12kg/ha. Potassium deficiency causes yellow discoloration at the tips of leaves (2nd left in Fig. 5 below) and ultimately dead leaves on clover (far right in Fig. 5 below); something that was very prevalent in clovers adjacent to panels. Collectively these things result in clover not being able to compete with other plants in close proximity to panels. It could be that fertilizer applications with high P and K may mitigate some effects, but ongoing accumulation of leachates will always be problematical.

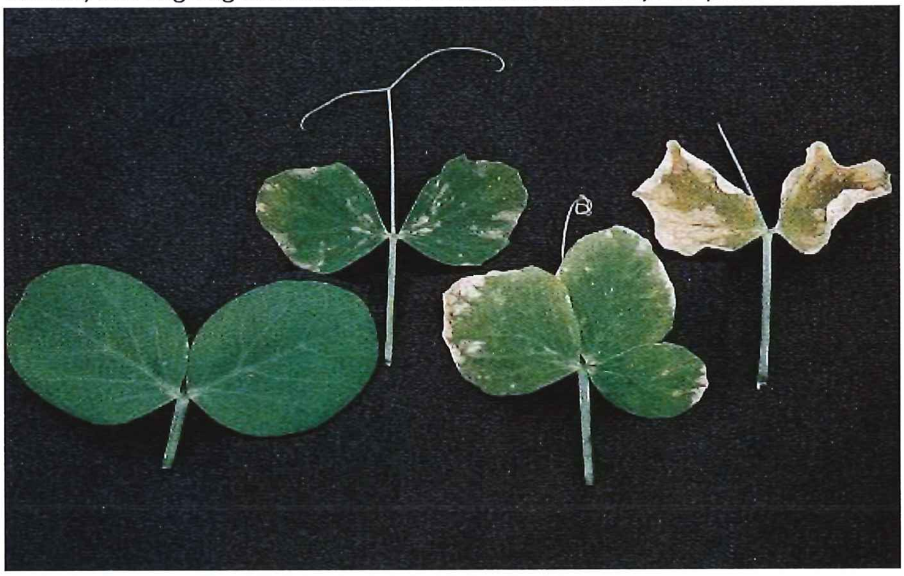


Figure 5. The increasing impacts of potassium deficiency on clover leaves (>15m from panels far left) to under solar panels (far right).

Different plants have differing requirements for phosphorous. Legumes, such as clover, require higher amounts of phosphate than grasses. Clover plants with phosphorus/phosphate deficiency have poor seedling and root development. Furthermore, with the destruction of root mycorrhizae by heavy metals, then the volume of soil from which plants can absorb phosphates is vastly reduced (Fig. 6).

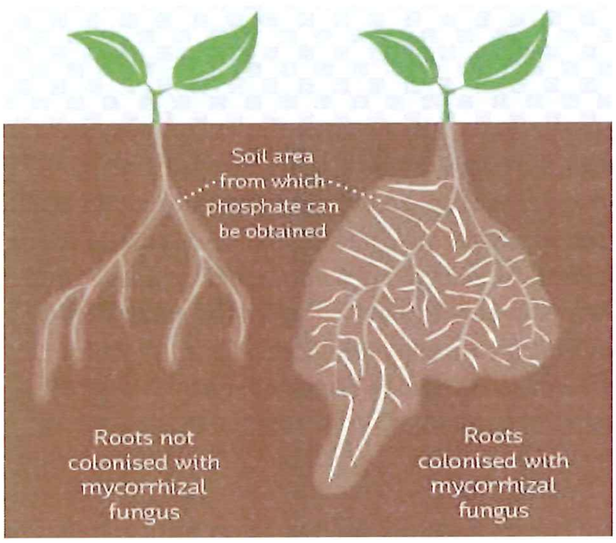
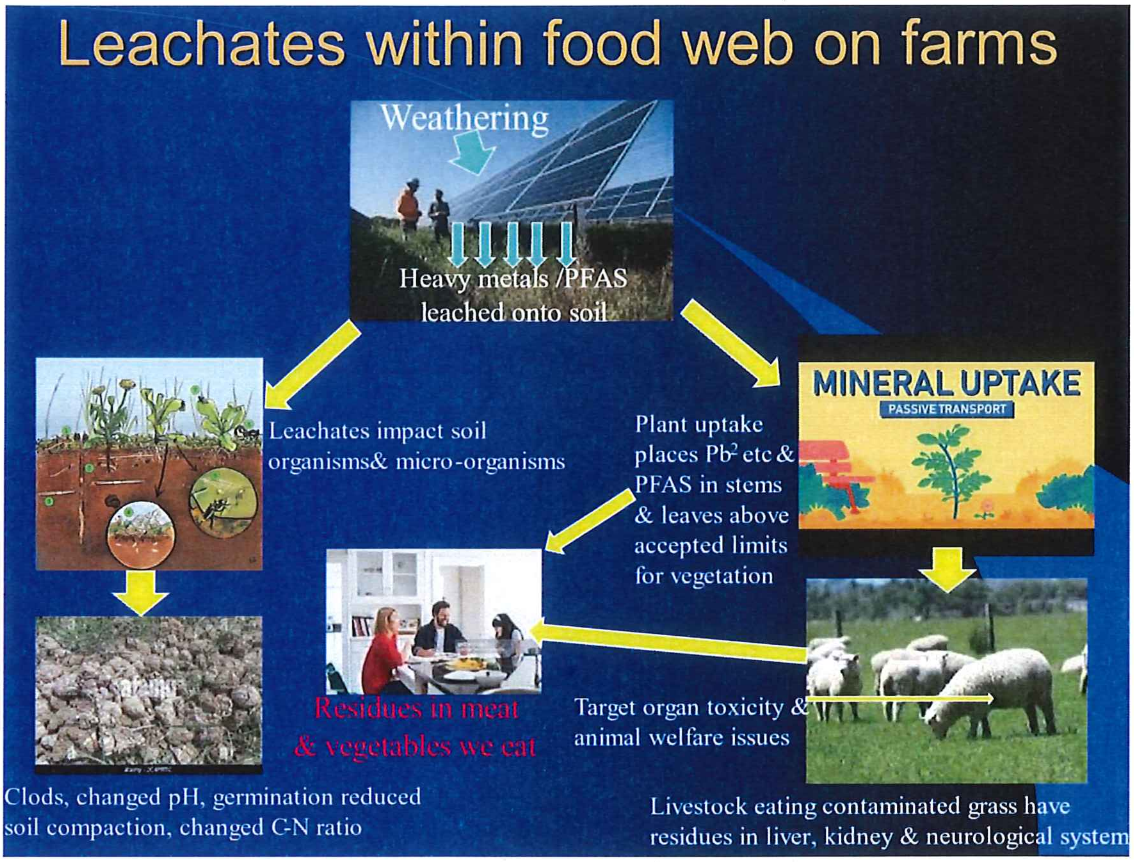


Figure 6. Loss of mycorrhizae because of heavy metals limits uptake of phosphates and potassium.

In this study added iron and other heavy metals from solar panels have killed over half the mycorrhizae in plant roots and reduced bioavailable potassium and phosphates; scenarios that create a "perfect storm" for the clover plant.

Impact of solar farms on agricultural food web

Contaminant transfer within the food web on farms is shown in photo 1 below.



Impacts of contaminants on sheep (this study)

The contaminants leached from panels have accumulated in heavy loams, and these in turn have bioaccumulated in ryegrass. These contaminants in grass when ingested by sheep as small sub-chronic doses present a significant risk to animal health because they are either at, or exceed, the recommended daily dose (Table 8). Unfortunately, we did not have the resources to evaluate toxicology (bioaccumulation of heavy metals in liver, kidney, muscle, and brain tissue of sheep) or histopathology (impacts on the cellular functions of tissue) of sheep, but this should be determined by Crown Research Institutes at long-established solar farms.

Table 10. Estimated daily intake of heavy metals by a 50kg sheep grazing under solar panels.

Contaminant	MAL mg/kg in humans	Daily intake by sheep m/k	Impacts on sheep	Impacts on health if sheep grazed long enough
Silica (Si)	not stated	unknown	Yes	When inhaled causes silicosis of lung, coughing.
Iron (Fe)	10	6.0	unlikely	Unlikely, half-life (HL) is only 0.5 day.
Boron (B)	0.2	0.1	unlikely	Unlikely, doesn't bioaccumulate (HL=1 day)
Aluminium (Al)	0.6 in H_20, 1 in food	2.5	yes	Neurological effects, possible necrosis of pulmonary, hepatic and renal tissue. Long HL.
Lead (Pb)	0.025	0.4	yes	Neurological effects; possible necrosis of renal and hepatic tissue. Bioaccumulates; long HL in tissue.
Arsenic (As)	0.001 in H_20 0.001 in food	<0.1	unlikely	The LOD for the test used on contaminants in ryegrass was too high to quantify risk.
Cadmium (Cd)	0.003 in H_20 0.1 in food	<0.01	unlikely	Leached cadmium is increasing in soil but not yet an issue. Bioaccumulates; long HL in tissue.
Manganese	Adults=2.3 Infant=0.6	16.4	yes	Neurological affects resembling Parkinson's disease; cardiotoxicity and hepatotoxicity.
Zinc	1	1	unlikely	Insufficient in plants; although long HL in tissue.
Copper	0.15	0.5	possibly	Impacts GI microflora, immune system, cytotoxicity.
Chromium III	1	<0.2	unlikely	The LOD for the test used on plants is too high to quantify risk. Long HL in tissue, bioaccumulates.
Chromium IV	0.0007			

Note: elevated arsenic, cadmium and chromium were elevated in soils, and may in time increase to levels in offshore. The maximum allowable limits (MAL) for boron has not been established, but the USEPA (2004) recommends dosage should not exceed 0.2 mg/ kg bw/day.

Livestock and humans (research from offshore)

What happens when animals eat plant matter containing high concentrations of heavy metals and PFAS contaminants? This has been assessed for pigs and sheep offshore, but not in New Zealand.

Pigs

The outcomes of moderate metal contaminants in Polish soils have been monitored by measuring contaminants in grain, and then contaminants in pigs that eat that grain. The pigs were fed a cereal-based diet grown in soils containing moderate amounts of heavy metals that (Chałabis-Mazurek *et al.* 2021).

Table 11. Contaminated soils in Poland grew grain that bioaccumulated heavy metals (mg/kg), which when fed to pigs resulted in elevated heavy metals in meat, liver, and kidneys.

Type of heavy metal in soil / food	MAL in meat (EU)	Contaminants in soils[1]	Contaminants in cereal used to feed pigs	Heavy metals in pig meat	Heavy metals in pig liver	Heavy metals in pig kidney	Wild boar livers contain high contaminants[2]
Cadmium	0.05	0.03 – 1.0	0.125	0.005	0.043	0.05	0.483
Lead	0.1	0.1 -40	0.147	0.09	0.756	0.60	0.195
Copper	0.5	0.01 – 50	27.3	13.7	30.5	35.8	
Zinc	0.3	5 – 150	179	128	230	116	63
Iron	0.5	50 – 3,000	207	81	486	185	
Manganese	n/a	0.02 - 0.5	94	1.2	11.3	6.2	
PFAS	0.7	n/a		1.4			117

[1] Tomczyk *et al.* 2023. [2]. Kasprzyk *et al.* 2020

These results show moderate concentrations of contaminants in soils are taken up by plants that then bioaccumulate heavy metals in grain; that grain when eaten by pigs causes leachates to bioaccumulate in their liver, kidney, and muscle. Almost all measured concentrations of heavy metals and PFAS in these pigs are above maximum allowable European limits for meat and animal by-products destined for human consumption.

Sheep

Unbelievably there has not been a comprehensive study on the histopathology or toxicology of tissues from sheep feeding under solar panels. All authors to date have evaluated the performance of sheep as growth rates of lambs and/or stocking rates under new panels (i.e., solar panels <2-years old) where there are low contaminant levels.

A study is required where solar technologies have been in place for 15-20 years, and the soils under those panels contain high levels of contaminants. Furthermore, there has not been a study undertaken where sheep have been grazed under solar panels for long periods. There has been research in Kuwait where live sheep were imported from Australia and stock ingested heavy metal contaminates from hard feed, soils, and plants for 2-12 weeks before being slaughtered (Abd-Elghany *et al.* 2020). This research showed alarming levels of mercury, arsenic, lead, cadmium, and chromium had quickly bioaccumulated in the meat, liver, and kidney; residues that were 3-6x the European MALs for meat and animal by-products (Fig. 7).

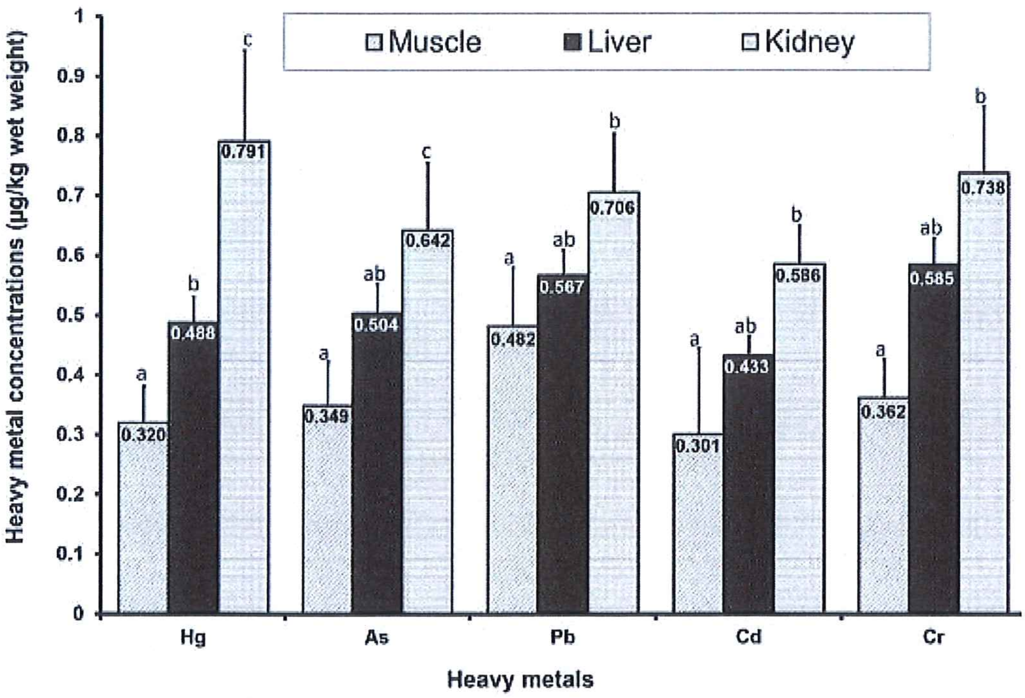


Figure 7. **Heavy metal concentrations (mean ± SE) detected in the investigated sheep tissues: muscle, liver, and kidney** (Abd-Elghany *et al.* 2020).

The meat and by-products from pigs and sheep in these 2 studies result in people similarly bioaccumulating heavy metals and PFAS. We are not going to speculate on the likely magnitude of this future problem for New Zealand, but certainly in China it now presents as a major health issue (Parvez *et al.* 2022).

Vegetables grown under panels

Brassicas were grown in soils containing 0%, 2.5%, 5%, 7.5% and 10% of the heavy metals in solar panels (Su *et al.* 2019). Measured amounts of contaminants from solar panels were measured after 30-, 60-, 90- and 120-days following planting. Commercial soils (pH≈7) spiked with 7.5 and 10% of the potential leachates from solar panels contained toxic levels of heavy metals after plants had grown for 60 days or more in soils. After 60 days at these concentrations plant growth was impeded by Al and so aluminium concentrations asymptote at 350 mg/kg. Even low concentrates of leachates (2.5% of that available in panels) eventually raised aluminium in plants above accepted standards.

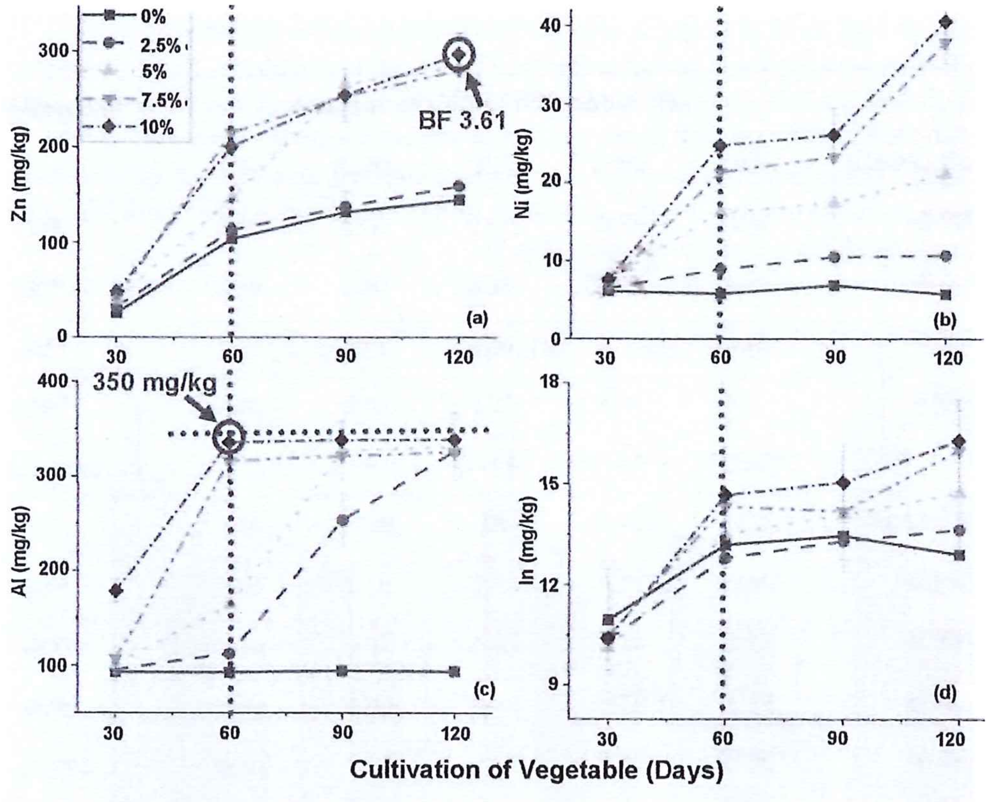
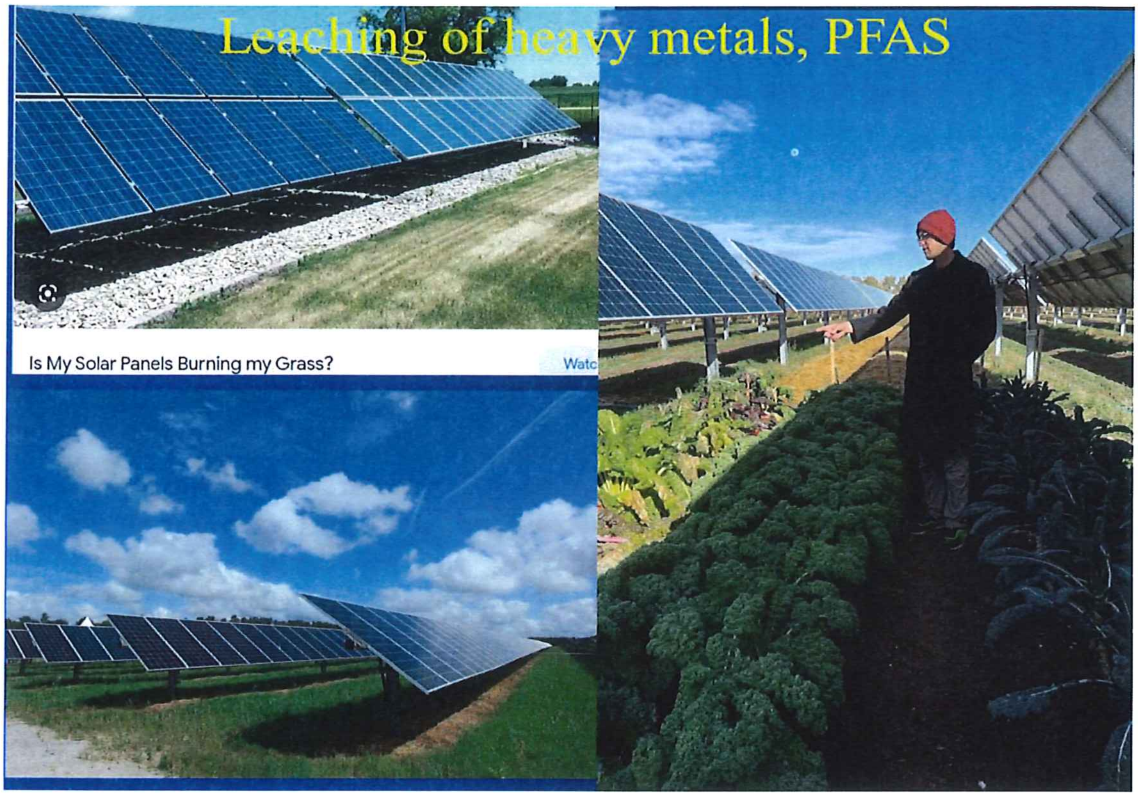


Figure 8. Uptake of zinc, nickel, aluminium, and indium by plants grown in soils containing 0, 2.5%, 5%, and 10% of the heavy metals from solar panels (Su *et al.* 2019).

Photo 2 below on the right shows a man pointing out brassicas growing in the "dripline" under panels that are severely impacted by leachates compared to the slightly healthier plants a metre away from panels.



All the plants under panels shown above contain high levels of contaminants that affect plant growth, and the health of humans that eat produce grown in that contaminated soil. The health impacts of some of these substances are summarized in Appendix 4.

The worst plants for bioaccumulating heavy metals are blackberry and briar. Blackberries grown in contaminated soils bioaccumulated 29x the permitted lead (Pb^{2+}) concentration, so 100g of this fruit per week over a month constitutes enough Pb^{2+} to cause nephrotoxicity and neurological symptoms of lead poisoning (Vlad *et al.* 2019). Wild rosehip berries (Zeiner *et al.* 2018) at contaminated sites had bioaccumulated on average 8242 mg/kg of aluminium (Al), 11.3 mg/kg of nickel (Ni) and 3.34 mg/kg of lead (Pb); all contaminant levels well above WHO guidelines. These concentrations of heavy metal will seriously affect birds that feed on these fruits. Both blackberry and briar grow wild at Brookside and will act as a vector for transmission of contaminants in soils, to contaminants in birds and other vertebrates.

Review of toxic effects of high metal leachates in this study

Iron (Fe)

Other than the impacts on soils and microorganisms outlined above that reduce bioavailability of nutrients to plants, it is unlikely high iron leachates will affect animals.

Iron becomes increasingly toxic to sheep in single doses above 25 mg/kg. At 40 mg/kg 1 of 5 sheep died in an experimental dose group; at 80mg/kg all 5 of 5 sheep died; with necropsy showing anorexia, loss of weight, diarrhoea, depression, symptoms of circulatory failure, pulmonary oedema, and respiratory failure (Rallis *et al.* 1989). The Rallis study measured acute toxicity where iron was administered in a single large dose. In this study sheep were eating ryegrass daily that contained 98mg/kg Fe so were consuming 300-400 mg of iron in chronic doses of around 6 mg/kg each day. For other types of heavy metal that bind to tissue this would be fatal, but because Fe has a half-life of only 5-20 hours in the liver (depending on the type of iron and mode of administration) much of the iron that is ingested is eliminated before the next meal of iron-laden grass.

Aluminium

1. In soils

It would be remiss to not include a discussion on the effects of aluminium on soils. All solar panels irrespective of type and manufacturer leach large volumes of two substances; silica and aluminium. Silica may be inhaled to cause silicosis of the lungs, or washed into surface waters where it gets into the gills of fish and slowly kills them. However, the consequences of more-and-more bioactive aluminium in soils are far more insidious.

Aluminium exists in many forms, with some encapsulated as aluminosilicates in soils, some encapsulated in an oxygen tetrahedron or oxygen octahedron, and some as non-labile aluminium salts. However, a percentage is always labile, and that percentage rapidly increases as pH falls outside a pH range of 5.5 – 7.0 (Fig. 9). As bioavailable aluminium is increased in soil then phosphorous/phosphates and potassium are occluded in much the same way as they are with iron, while some aluminium also bonds with phosphorous/phosphates to form $AlPO_4$ or AlP. As aluminium becomes progressively more bioactive in soil, then total bioavailable nitrogen in unfertilized soil progressively falls (Fig. 10) as does the growth of many families of plants because root growth is impaired by high concentrations of aluminium (Whitley 2018).

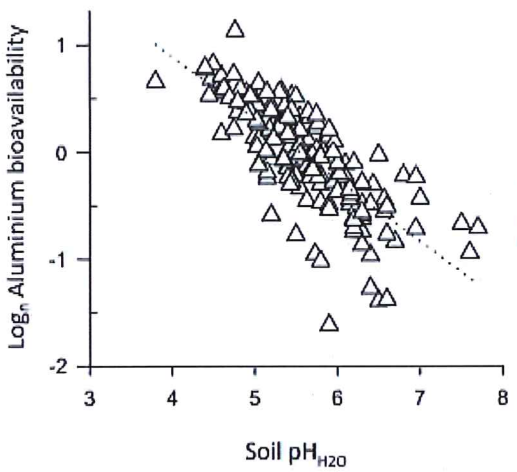


Figure 9. Aluminium bioavailability in soils increases outside a pH range of 5.5 – 7.0).

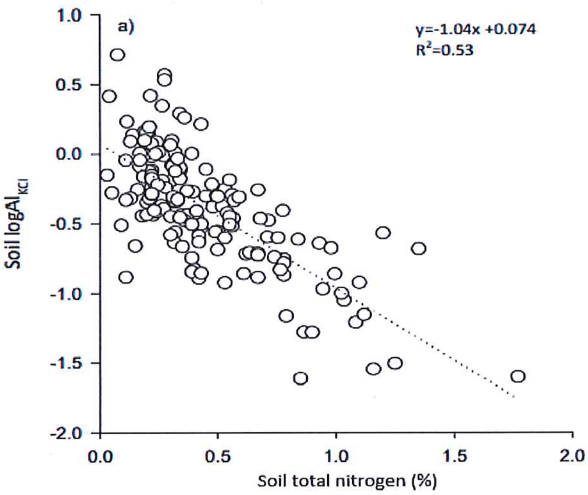


Figure 10. The decline in total nitrogen in soils as aluminium is increased.

Aluminium is hydrolysed (and this adds to soil acidity) before it is either adsorbed onto roots or absorbed into the root as one of the hydroxides:

$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$

$Al^{3+} + H_2O \rightleftarrows Al(OH)^{2+} + H^+$

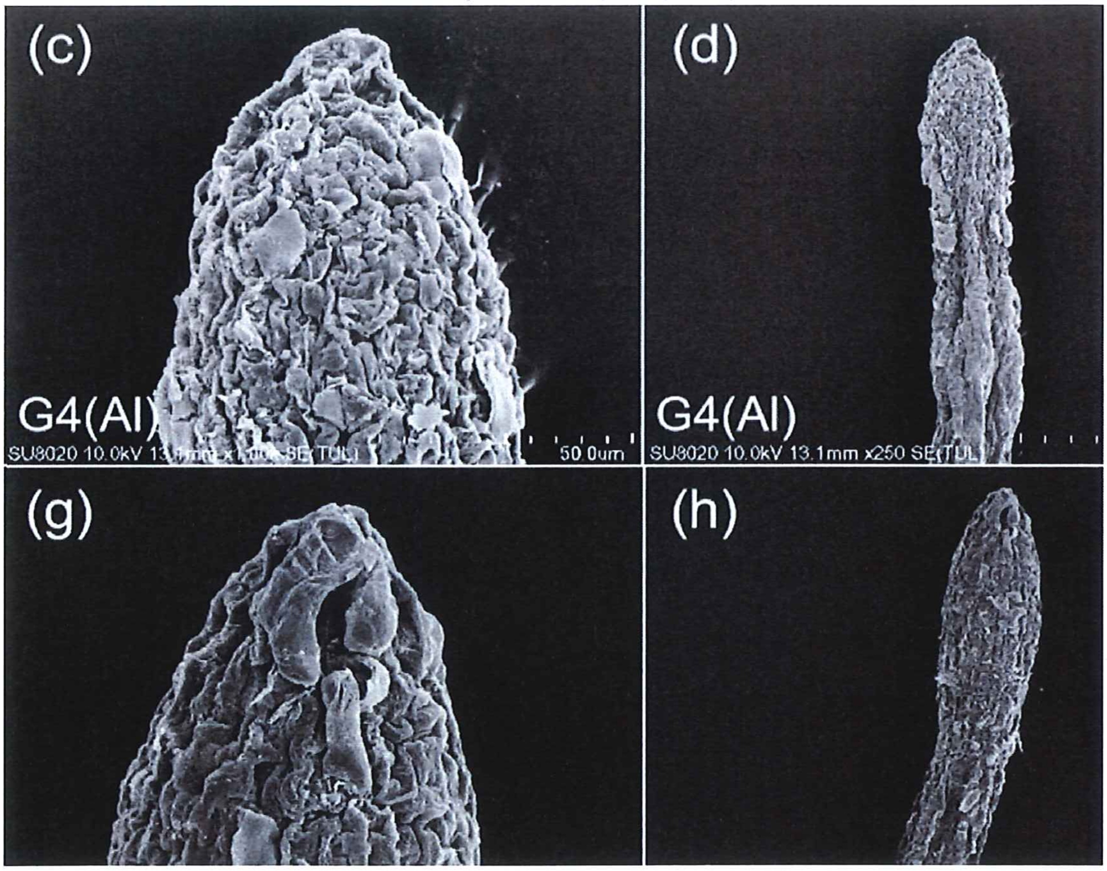
$Al(OH)^{2+} + H_2O \rightleftarrows Al(OH)_2{}^+ + H^+$

$Al(OH)_2{}^+ + H_2O \rightleftarrows Al(OH)_3 + H^+$

$Al(OH)_3 + H_2O \rightleftarrows Al(OH)_4{}^- + H^+$

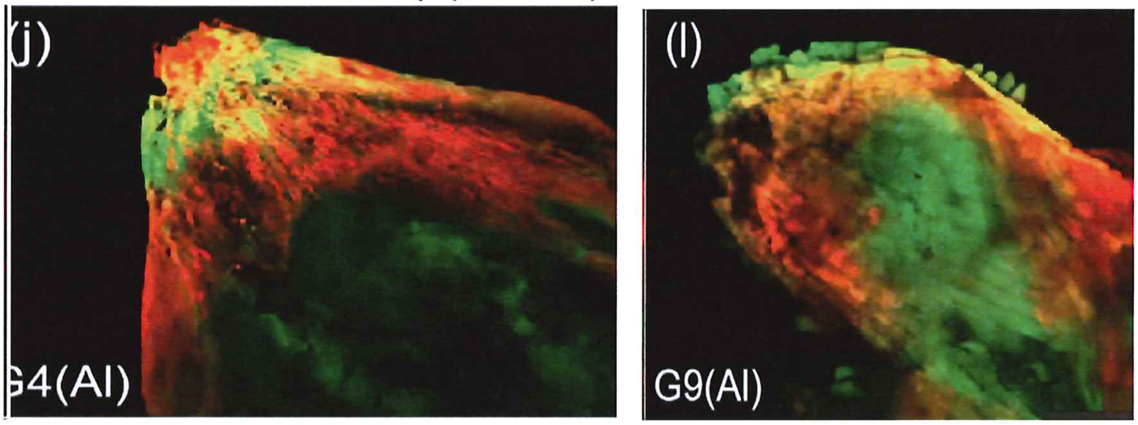
At low pH (i.e., <5.5), large amounts of Al mainly as Al^{3+} bind to the roots and inhibit root growth, they damage root tissues, and causes deficiencies of Ca, Mg and P in plants as well as other physiological stresses (Collignon *et al.* 2012). Other forms of labile aluminium adhere to symplasm (the continuum of cytoplasm) near the root surface, and this prevents uptake of nutrients (Delhaise *et al.* 1995). Furthermore, when Al is aggregated at the root tip this not only impedes root growth and uptake of nutrients (photos **c** & **d** below) but kills root cells (photos **j** & **l** below). Plants depend on the beneficial interaction between the root and microorganisms to obtain an unobstructed supply of nutrients (photos **g** and **h** below), to grow, and to inhibit disease (Edwards *et al.* 2015). This is especially true for clovers. During this study mycorrhizae and root development of clovers were increasingly impeded as concentrations of leached Al from solar panels increased in soils. The heavy metals in soils kill some mycorrhizae, and ultimately aluminium causes deficiencies of key nutrients (e.g., potassium, phosphates, magnesium, calcium) and kill the plant as well. The photos below show the buildup of aluminium on roots (c and d) compared to healthy roots (g and h).

Photo 3: Aluminium adsorbed to plant roots (c & d) compared to healthy roots (g & h).



Aluminium kills root cells (stained red) near the root tip (*below*), and this not only reduces root volume, but impedes root growth compared to healthy cells (showing green under UV fluorescence).

Photo 4: **Dead cells on root tips (stained red) under adsorbed aluminium.**



Aluminium that is absorbed into plants as one of the hydroxides impedes cell division and plant growth, decreases plant respiration, interferes with enzymes governing the deposition of polysaccharides in cell walls, decreases the synthesis and transport of cytokinins (substances that promote cell division and cell growth), and modifies the structure and function of the plasma membranes that facilitate uptake, transport, and use of multiple elements (Ca, Mg, P, and K), as well as water uptake by roots of plants for transpiration and photosynthesis (Foy 1974, Foy *et al.* 1978, Kochian *et al.* 2004).

Once aluminium reaches critical concentrations in soils then it is difficult to remove, and farm management becomes reliant on use of crop species that are resistant to aluminium (specialist varieties of wheat, barley, ryegrass), and the careful management of soil acidity with appropriate liming to keep pH in a range 5.6 – 7.0. Legumes (e.g., peas, beans, clover) will always be very susceptible to elevated aluminium in soils.

2. Aluminium in aquatic ecosystems.

Aluminium has a HSNO of 9.1A because the hydroxides of the substance are very hazardous to algae and the gills of fish. Generally, concentrations in water relate to dissolved Al $(OH)_3$ because this is the most common form at pH 6.6 -7.2 (i.e., the pH of normal river or lake water). In a measure of acute toxicity of Al to trout it was found that most were sensitive at concentrations above 0.5ppm and that it was lethal at 1.5 ppm (Freeman *et al.* 1971).

3. Aluminium in ruminants.

Unfortunately, we did not have the resources (mainly time) to do blood chemistry, toxicology, and histopathology on the sheep grazing under panels in this study. Although I could not find a detailed study on aluminium in sheep, a very good paper has been written on the toxicokinetics of aluminium in Nubian goats (Medani *et al.* 2011). This research showed 1% aluminium sulphate (alum) in drinking water significantly changed blood chemistry with changed enzymatic activities of ALP (liver & bone function), AST (liver function), CK (muscle & heart), ALT (damage to liver cells)) and LDH (tissue damage) all changed, with metabolic changes also found in albumin, urea, total protein, cholesterol, bilirubin, glucose, and creatinine. Fluctuations in electrolyte levels of Mg, Fe, Na, K, Ca and P were recorded together with haematological changes in Hb (haemoglobin), PCV (blood cell count), RBCs and WBCs. Mortalities occurred to variable degrees irrespective of the dose of aluminium ingested. The goats showed clinical signs of low voice, inappetence, dullness, whitish salivation, watery diarrhoea and recumbency. The lungs maintained residual aluminium in pulmonary tissue, while the livers washed out the substance (maybe via bile). Notably oral dosing with aluminium caused congested livers with white spots, stiff-greenish lungs and inflamed empty intestines. Histopathology showed necrosis in the cortex and medulla of the kidney, emphysema in the lungs, necrosis in the hepatocytes, and congestion in the liver of all animals. On evaluation of results, aluminium sulphate was considered toxic to Nubian goats at all dose rates ingested. Although every paper on agrivoltaics talks of grazing ruminants (sheep, cattle, goats) under solar panels, there is nothing to confirm that this has negligible impacts on animal health when we know every type of solar technology leaks both aluminium and lead onto pasture. During this study it appeared that sheep were laying down more frequently following a month of grazing under panels, but there were no other clinical signs.

The other impact on the viability of grazing under panels arises from sheep rubbing on zinc galvanized supports for solar panels. The wool of sheep becomes badly stained, and the fleece considerably devalued. Once again this is yet another blemish to the "100% pure" label that was a hallmark for New Zealand produce during years gone by.

Photo 5. Wool staining from sheep rubbing on aluminium.

Photos of the wool on sheep after grazing under solar panels on the property of Michael Dalley. 'Wool staining' has happened from sheep rubbing on aluminium.

Sites for solar farms

1. Leachates from solar technologies

The mobility of carbon (from fires) through topsoil and subsoil (Fig. 11) was measured for sandy soils (where movement of added leachates out of soils was rapid) and loams (where added leachates remain suspended in the root zones of plants for extended periods of time). As has been demonstrated during this research, solar farms leach large volumes of heavy metals and PFAS onto soils, and the movement of them through soils is regulated by soil type. In the case of compacted loams leachates either remain on the soil surface (where they are washed into streams by floodwater), or they are taken up by plants and enter the food web of terrestrial vertebrates.

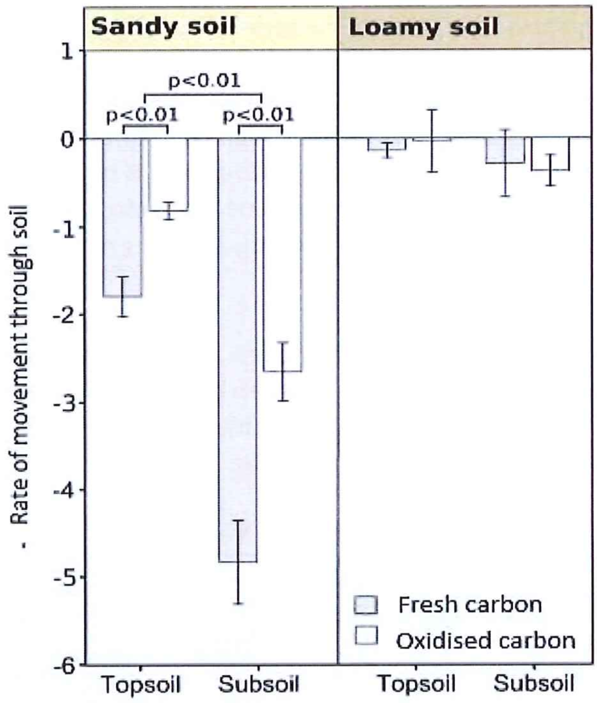


Figure 11. **The rates of migration of pyro-carbon leachates through sandy soils and loams (*from* Schiedung *et al.* 2020).**

In a further experiment, the effects of added iron and aluminium into loams were shown to further reduce the permeability of soils to both water (viz. increases run-off of floodwaters) and heavy metals (Fig. 12).

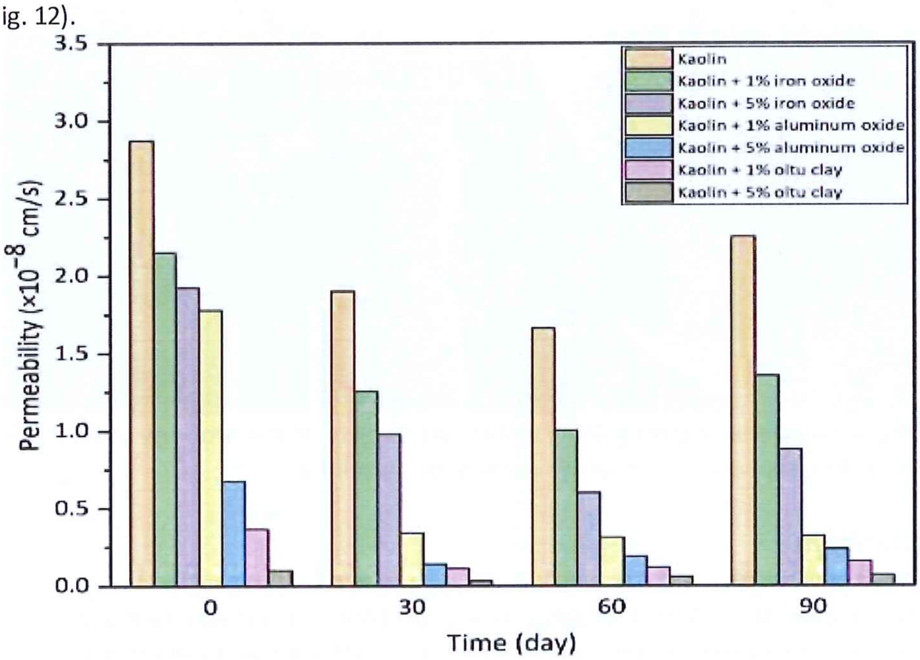


Figure 12. **The permeability of kaolin soils is progressively reduced with the compounded effects of added iron, added aluminium, and added clay into topsoil (*from* Özçoban *et al.* 2022).**

These two factors outlined in Figures 11 and 12 above (i.e., i) the very low migration of leachates added to soils through loams compared to sandy soils, and ii) clod formation in loams with the addition of Al and Fe) reduces the movement of heavy metals and/or PFAS leachates out of topsoil. This suggests the choice of site for a solar farm is critical. In a lighter, sandy soil, the leachates from panels will rapidly disappear from the root zone of plants and migrate deep underground where they either remained buried or get into groundwater. In a heavy loam, leachates will remain near the soil surface or be washed into streams. Critically, leachates from panels taken into the loams at Brookside remain in the root zone of plants (which enables them to be absorbed and to then bioaccumulate in plant tissue, fruits, and the seeds of plants), and when this vegetative matter is subsequently consumed, they then bioaccumulate in the tissues of birds and animals. The heavy loams at Brookside with added iron and aluminium make this a poor site for a solar farm.

GIS (global information systems) have been developed that weigh the risks, costs, and benefits of siting a solar farm on agricultural land as opposed to degraded soils. There have been numerous papers written on where solar farms could be sited. These include a) the sites of old landfills (USEPA 2021), b) sites where soils are degraded and not suited to agriculture, and c) where there are light permeable soils that rapidly facilitate the movement of heavy metals and PFAS out of topsoil. Meta-analysis of over 40 science papers written on the siting of utility scale solar photovoltaic facilities (Fig. 13) stated that "lands that are protected, lands that are cultivated and productive, and land alongside watercourses are sites considered to have the highest restriction factors against solar development described in the literature" (Garni *et al.* 2018). The 4th highest factor that precludes siting a solar farm at any location is residents living alongside the site.

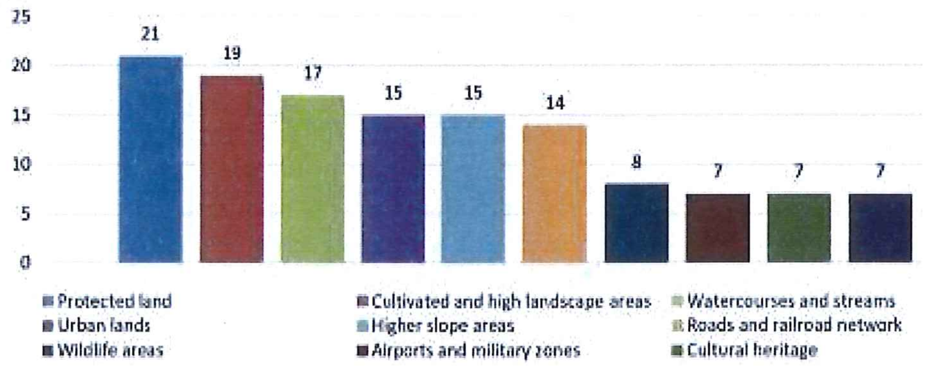


Figure 13. The worst factors that prevent the use of a site for a solar farm (from Garni *et al.* 2018).

It just so happens the site of the proposed Brookside solar farm is:

a) Protected by the NPS-HPL;
b) Is cultivated land that is irrigated and highly productive;
c) Is situated on the banks of a waterway that drains into Lake Te Waihora; and,
d) Is in an area where a high number of ratepayers reside (94% of whom are opposed to the solar farm).

In effect, Brookside is the worst possible place to site a solar farm.

Legislation
Despite known environmental risks, despite published science that quantifies these risks, despite government statutes and policy statements made with good intent, and despite local authorities being entrusted with the best interests of communities and the environment; the development of a solar farm at Brookside has proceeded to a 2nd hearing. A previous commission hearing on this project indicated that environmental risks and risks to highly productive lands by contaminants required that a resource consent be "publicly notified". In his summing up Commissioner Hughes-Johnson stated in clause 10.21: "Having regard to the findings which I have made earlier in this my decision relating to the environmental effects of the Proposal (which I will not repeat here), and noting my finding that the loss of productive potential in the sense to which I referred to this matter earlier in this decision gives rise to environmental effects which are more than minor, I am required to decline to grant a resource consent in this case because of my view that the application should have been the subject of public notification and was not".

This research was undertaken on "highly productive land" and demonstrates shortcomings in the polycrystalline solar panels on Michael Dalley's property that were once regarded by the solar industry as one of their "elite" solar panels. That solar panel along with other apparatus will eventually render productive heavy loams as unproductive soils that are repositories of large quantities of heavy metals and PFAS contaminants.

1) Impacts within NPS-HPL policy statement.

What has been unequivocally demonstrated at this moment in time is that leaching of heavy metals onto 'Highly Productive Lands' changes soils. At this Brookside site solar panels have changed the NPK of soils, increased nitrogen-nitrate concentrations, lowered soil pH, and increased iron to a level where it creates clods, causes soil compaction, changes water dispersion, increases water run-off, and occludes phosphate and potassium. The cumulative effects of all added heavy metals will reduce the abundance and diversity of soil micro-organisms. The iron facilitates soil compaction of topsoil and may ultimately result in an iron pan. There are increasing levels of contaminants in ryegrass that will be ingested by sheep, and contaminated pasture contains few clovers. Ultimately, soils will become a lot less productive than existing soils with no solar panels. All this is counter to what is contained in the national policy statement on highly productive lands.

In the model 'Risks=Hazards x Exposure' where hazards from contaminants are 'high' we have demonstrated for soils that 'exposure' is 'high'. Consequently, in the model for risk analysis we have 'Risks=High x High. Therefore, the risks to "highly productive lands" are high, and accordingly a consent for the activity should not be granted.

2) Reverse sensitivity effects

Existing activities around the site of the solar farm will be affected by run-off of contaminants in surface waters onto surrounding farmland. These contaminants will not be distributed uniformly, but clustered in gullies and hollows, while other areas will only be slightly affected. The exposure of these neighbouring properties will therefore be "moderate" (i.e., somewhere between highly affected and slightly affected). In the model 'Risk=Hazard x Exposure', the equation becomes Risk=High x Moderate (i.e., moderately high). With moderately-high reverse sensitivity effects on surrounding farmland a consent for the activity should not be granted.

3) Impacts within NPS-FM

i) Heavy metals

Previous research has monitored both surface waters and groundwaters in China where large USSP facilities have been established for long periods of time (>20 years). At all sites contaminated by the types of heavy metal used in solar technologies there has been a dramatic rise in the presence of these substances in river water during the 21st century (Fig. 14).

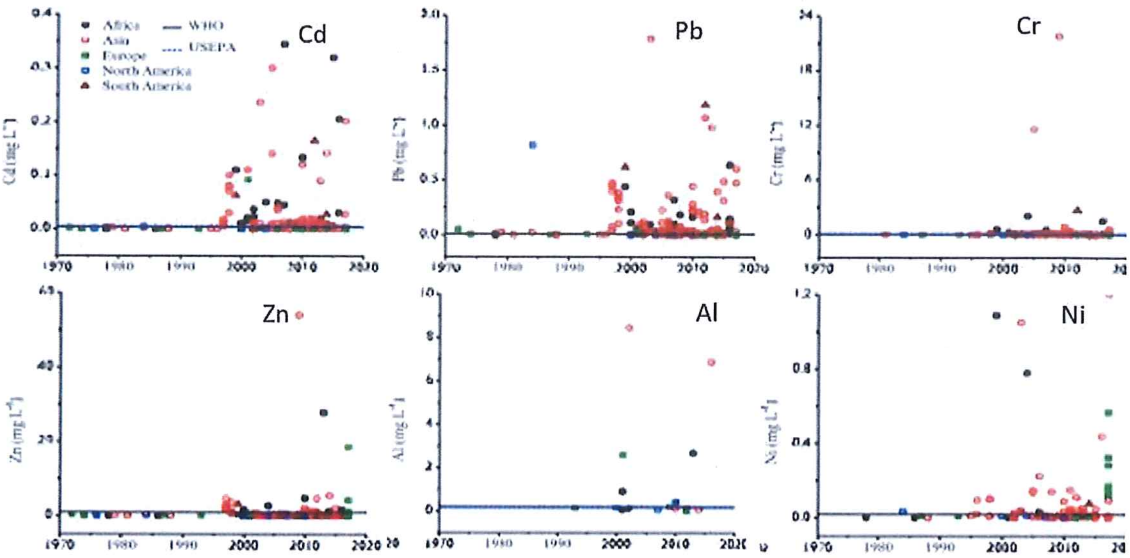


Figure 14. A review of heavy metals in rivers and lakes shows a dramatic rise of Cd, Pb, Cr, Zn, Al, Ni, as well as other leachates from the late-1990s as solar farms became established in China in particular. These heavy metals are deposited on soils, dispersed as airborne particulates during a fire, and washed into surface waters (Zhou *et al.* 2020).

Ecologists have monitored the impacts of heavy metals on the food web of aquatic organisms. Results show they kill many small aquatic organisms (e.g., *Daphnia* or water flea, and fish embryos) at low concentrations in water (0.3 – 4.3 mg/L; Kwak *et al.* 2021); they bioaccumulate in aquatic plants like watercress (Phillips *et al.* 2011a), and they bioaccumulate in large freshwater fish at the top of the food-chain (e.g., eels, trout, flounder). In New Zealand, only a few studies have monitored the impacts of freshwater contaminants on aquatic organisms and their uptake by humans, but in the Te Arawa lakes around Rotorua there are unacceptably high concentrations of heavy metals in freshwater kai eaten by Maori (Phillips *et al.* 2011a) that impact human health (Phillips *et al.* 2011b). At the Te Arawa lakes site the concentrations of heavy metal contaminants was highest in filter feeders (mussels and pipis where watersheds drained into the ocean), koura (freshwater crayfish) contained high levels of metals, and trout and eels had concentrations of each substance in kai correlated with both the abundance of each contaminant in water, and its ability to bind to tissue and bioaccumulate (Philips *et al.* 2011a). Materials found in high concentrations in fish included cadmium, mercury, arsenic, selenium, zinc, copper, lead and nickel. These are the same substances leaked from solar technologies. Hair samples from people eating these contaminated foods contained elevated levels of heavy metals. A more detailed study in Europe demonstrated that people eating freshwater fish containing high levels of cadmium, mercury, arsenic, selenium, zinc, copper, lead and nickel experience high rates of cancer in addition to many other serious health effects (Panda *et al.* 2023).

It is inevitable that the siting of solar panels alongside waterways at Brookside will result in heavy metal contamination of drains and creeks that flow down into Lake Ellesmere, and that both fish and waterfowl that are kai for the local runanga of Ngai Tahu will become contaminated.

ii) PFAS
Per-and poly-fluoroalkyl substances (PFAS) are found in solar panels, in the insulation of wiring, in circuit boards, and in batteries. They are a class of "forever chemicals" proven to bioaccumulate in aquatic organisms. Fish harvested from streams in the USA by recreational fishermen are now so contaminated with PFAS that a recent publication demonstrated "a single fish harvested from freshwater presents more of a risk to that person's health than that person drinking PFAS contaminated water for a month" (Barbos *et al.* 2023). The reason for this is fish bioaccumulate PFAS over a long period from a contaminated ecosystem, and concentrates of hazardous substances are then eaten by humans. The worst-case scenario for release of PFAS at a solar farm is a fire burning encapsulants on solar panels, burning PFAS in wiring, or a fire in batteries that releases large volumes of PFAS into the air that then settles on soils. These PFAS are then washed off compacted soils into waterways and down to Lake Ellesmere during heavy rainfall.

For contaminants in freshwater, this study has not quantified risk, and to do so would require much more detailed research. Undoubtedly, over the course of 35 years (i.e., the initial duration of the project) tonnes of contaminants will be washed into streams surrounding the proposed site of the solar farm. In the model 'risks=hazards x exposure' where hazards are high, we have demonstrated a tangible but yet to be quantified 'exposure'. What the study has shown is a qualitative risk to freshwater, so under the NPS-FM a consent for the activity should not be granted.

4) Impacts on Conservation.
The streams adjoining the proposed solar farm contain the endangered mudfish (*Neochadda apoda*). The Department of Conservation has signs up along the creek adjoining the Brookside solar farm to notify the public of their presence (*see* Photos 6, 7 below). These species will be especially vulnerable to heavy metals and PFAS washing off a solar farm during heavy rain and some will undoubtedly be killed by positioning a solar farm at its intended location.

Under the Conservation Act 1987 and Conservation (infringement system) Act 2018 it is unlawful to knowingly endanger or kill a "threatened species" by poisoning it with materials known to be hazardous to that species. Yet that is precisely what a solar farm at Brookside will do.

Photo 6.

Photo 7

5) Impacts on vertebrate ecosystems.
During 50-year period 1970-2020 the abundance of birds on Planet Earth has declined by around 65%; with heavy metals (19.5%) and PFAS (8%) causing over a quarter of that man-made decline

(Richard *et al.* 2021). In the model "Risks=Hazards x Exposure" the known hazards to avifauna are high (*see* Table 7 above; HSNO=9.3A & 9.3B). How then are birds exposed? The research cited above demonstrates that blackberries, rosehip berries, grain, seeds (e.g., ryegrass seed), nectar, earthworms, and other invertebrates all bioaccumulate heavy metal contaminants from leachates deposited on soils. PFAS are also bioaccumulated in the same foods eaten by birds.

a) Primary poisoning.

Birds that feed on all this natural biota at a solar farm then bioaccumulate heavy metals and PFAS in their bodies. These heavy metals slowly debilitate the immune system of birds leaving them vulnerable to disease, and this results in population die-off. Eggs from females containing high metals and/or PFAS are thin-shelled with frequent egg-breakage in the nest; and those chicks that do hatch have been incubated on albumen with high lead, cadmium, arsenic, chromium and aluminium and so they struggle, with only a few surviving to maturity.

b) Secondary poisoning.

Mice and rats feed on blackberry, rosehip berries, grain, seeds, invertebrates, and bioaccumulate heavy metals and PFAS from these foods; the raptors (owls, hawks, falcon) in an ecosystem then feed on these rats and mice and bioaccumulate toxic substances. Raptors are recognized as the most vulnerable in the food web to "forever chemicals". The eggs of raptors contaminated with heavy metals and PFAS are less viable (Monclus *et al.* 2020), hatchlings have poor survivorship, fewer birds are fledged, the longevity of adults eating contaminated foods is reduced (Espin *et al.* 2016), the immune systems of birds are compromised (Bichet *et al.* 2013), impacts on DNA change birds morphologically (Albayrak *et al.* 2021), there is nephrotoxicity, hepatotoxicity, impaired growth, and for each genus of raptor the list goes on and on. Below we present two graphs: a) the first is from Sweden where less than 1% of energy is solar and since the removal of lead from petrol there has been a slow but steady decline in lead (Pb) in raptors over the past 40 years (Fig. 15); and, b) the second is from Spain where solar energy evolved from the late 1990s until by 2018 around 43% of their energy was solar. Figure 16 shows a steady decline in lead (Pb) in kestrels until 2000, and then the Pb in kestrels dramatically increased as Pb from solar panels entered the environment and leachates progressively contaminate rodents that the kestrels feed on. The graphs for other heavy metals in kestrels (Cu, Cr, Li, Ni, Zn) are almost identical to that of lead (Pb) because these are all leachates from solar panels. It is self-evident that if you want to poison your raptors, then solar farms contain all the hazards that will do that.

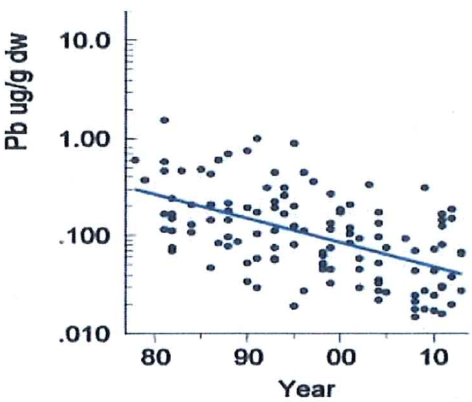


Figure 15. Measured lead (Pb) in raptors in Sweden (Helander *et al.* 2019).

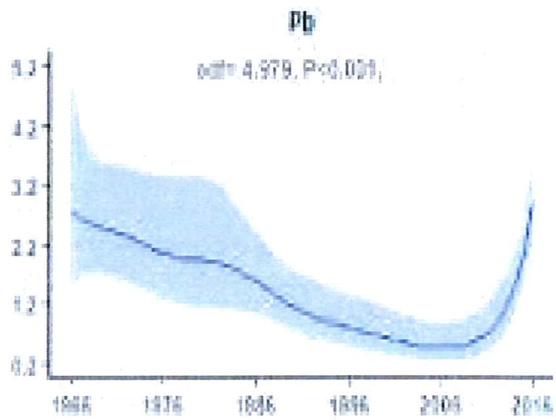


Figure 16. Measured lead (Pb) in raptors in Spain (Manzano *et al.* 2021)

At Brookside we have the little German owl and harrier hawks that will accumulate heavy metals and PFAS. In our model 'Exposure' is moderate (depending on bird species); and accordingly, risk (hazard x exposure) becomes a multiplier of "high" x "moderate" = moderately-high. Therefore,

risks to terrestrial vertebrates are significant (HSNO=9.3B), and under the RMA 1991 the resource consent application should be declined.
Contamination of aquatic ecosystems has serious implications for fish and other aquatic organisms. The birds most affected will be the waders (e.g., Royal Spoonbill, herons, etc) that feed on contaminated aquatic organisms. Inevitably after 20 years of the solar farm we will see some mortality of birds at Te Waihora.
The health and welfare of birds and other terrestrial vertebrates are compromised through the impacts of heavy metals on their neurological systems, immune systems, cardio-respiratory system; they cause nephrotoxicity, hepatotoxicity, impaired growth, and induce changes to DNA. Under the Animal Welfare Act this should not be a permitted activity and the resource consent application should be declined.

6) Treaty partnership for co-governance of Te Waihora

a. History of lake degradation

The traditional name for the lake was *Te Kete Ika o Rākaihautū* meaning "the fish basket of Rākaihautū". The food sources at Lake Ellesmere / Te Waihora were once abundant and included *tuna* (eels), *pātiki* (flounder) and *aua* (mullet). Te Waihora was also a famed *mahinga manu wai māori* (place for taking waterfowl). However, in a brief period of 50 years Te Waihora has gone from a state where it was described as "the finest shallow-water fishery in the southern hemisphere" (Ferris 1954) to the 2nd most degraded and polluted lake in New Zealand (Verburg *et al.* 2010). Although discharges of dissolved nitrogen and phosphorous in subterranean gravels are the main pollutants (Gibbs & Norton 2012) contributing to water turbidity and eutrophication, there have also been discharges of heavy metals, microplastics, and bacteria (e.g., *E. coli)* from influent waters entering the lake from the Selwyn, LII and Halswell Rivers. The rate of eutrophication in recent years has been enhanced by the Central Plains Irrigation scheme (consented by ECan), which is estimated to increase total nitrogen and total phosphorous in the lake by a further 20-40% (Gibbs & Norton 2012).

b. Governance of the Lake.

Until European occupation, the *rangatiratanga* (ownership) of the lake was vested in Ngāi Tahu and more specifically the local Runanga of Te Taumutu living at the southern and northern ends of the lake. European occupation made little difference to the disposition of the lake until wetlands surrounding the lake were drained and the Wahine Storm during 1968 destroyed macrophyte beds; mechanisms that filtered, oxygenated, and harvested nitrates and phosphates from the lake. What then followed was a massive rise in agricultural run-off in gravels beneath the sub-soil that surface in Te Waihora. Under the Ngāi Tahu Claims Settlement 1998, ownership of the bed of Lake Ellesmere / Te Waihora was returned to Te Rūnanga O Ngāi Tahu. Maori understood that lake restoration is reliant on prudent management of consents, district plans by councils, and so a co-governance agreement was signed in 2019 between Ngai Tahu and government agencies (Canterbury Regional Council, Selwyn District Council, Christchurch City Council, and the Department of Conservation). There are specific provisions in the co-governance agreement to improve the health of the lake and the quality of kai harvested from the lake by Maori.

c. The Brookside solar farm and Maori consultation

Apparently Maori consultation between KEA-X Ltd and Maori focussed on a potential reduction of nitrates washing off dairy farms at Brookside (Liz Brown *pers. comm.*) and how a solar farm may improve water quality at Te Waihora. Because most nitrates enter the lake as subterranean influents, reference to nitrates arising in spring waters around Brookside was little other than a red herring. Mr McMath made reference to reduced nitrates in his evidence statement presented during February 2023. The research outlined in this paper demonstrates that a solar farm will in fact make no difference to the efflux of nitrates from Brookside lands. However, what a solar farm will result in is the addition of heavy metals and PFAS that are washed into creeks and down to Te Waihora. The impact of heavy metals and PFAS was never discussed with Maori.

d. Heavy metals and PFAS in kai

Surprisingly, there has not been a detailed study of existing heavy metal contamination in kai at Te Waihora. Councils in the past have consented discharge of sewage containing contaminants into the lake, discharge of stormwater, and there is discharge of contaminants in floodwaters flowing off agricultural land into the lake.

Two detailed reports have been prepared on the quality of kai consumed by Maori from Te Arawa lakes (Rotorua District), and kai from the confluence of outlets from the lakes with the sea (Phillips *et al.* 2011a & Phillips *et al.* 2011b). These reports show that filter feeders (mussels and pipi) are highly contaminated, koura (freshwater crayfish) are contaminated, and both trout and eels are contaminated to the extent they present a significant risk to the health of Maori (Table 12).

Table 12. Mean metal contaminants (mg/kg) in Maori kai harvested from Te Arawa lakes district.

Heavy metal	Pipi/Mussels	Koura	whitebait	Smelt	Eel	trout	Watercress
Arsenic	10.2	4.1	4.4	1.25	0.62	0.24	1.1
Cadmium	0.45	0.04	0.083	0.02	0.02	0.003	0.06
Chromium	8.8	<0.10	0.25	0.54	<0.1	<0.01	0.59
Copper	4.8	31.4	2.7	2.2	1.2	1.1	5.3
Lead	0.21	0.02	0.55	0.26	0.013	<0.01	0.38
Mercury	0.11	1.92	0.073	0.84	2.3	3.6	<0.01
Nickel	6.2	<0.01	0.36	0.43	<0.1	<0.01	0.24
Zinc	62.2	78.2	120	206	53	19	120

These traditional foods taken from surface waters around Rotorua presented a high risk to the health of Maori (Table 13). Given the current levels of heavy metal contamination of kai, Maori in the Te Arawa lakes district are eating too much watercress, and too many trout, pipi, mussel, and eel. As stated above these environmental contaminants do not present a risk as a single meal, but eaten in small, divided amounts over several months they bioaccumulate and cause cancer, neurological effects, and other health issues (e.g., nephrotoxicity, hepatoxicity, etc).

Table 13. Estimated median and low health risks from a set number of meals per month of traditional kai by Maori (Phillips *et al.* 2011b).

Kai species FW=freshwater	Risk-based consumption limit (**median** risk as meals eaten per month)	To **minimize** health risk to the 95% quartile the meals per month of traditional kai are listed below	Actual consumption rate (meals/month)
Trout	**0.9**	**0.4**	**1.5**
Koura	4.7	1.6	0.5
Eel	1.9	1.1	1.3
Smelt	2.6	2.0	0.6
Whitebait	1.8		0.6
Pipi	**2.6**	**2.2**	**3.5**
Kakahi (FW mussel)	1.3		0.1
Mussel	**2.9**		**3.5**
Watercress	**1.0**		**3.1**

Unfortunately, the Selwyn District Council in partnership with Mahaanui Kurataiao have not correctly assessed a change in land use from dairy farming to an industrial site on ecosystem health at Te Waihora. Their rationale for changed land use was an infinitely small reduction in nitrates entering the lake through reduced dairy farming at Brookside as opposed to the >80% of nitrates that enter through underground aquifers. Although of little consequence this study demonstrates nitrogen leached from panels will increase that small efflux of nitrate-nitrogen from Brookside into Te Waihora. Of more concern are the heavy metals and PFAS draining into the lake over a 20-30-year period that will seriously contaminate kai harvested as traditional foods by Maori.

From this research we cannot quantify risk to people from a solar farm at Brookside (i.e., will 1, 2 or 5 people eventually die each year from contaminated kai). What we can say qualitatively is that the solar farm will have a tangible effect on kai (trout, flounder, eel, whitebait, and watercress) harvested from waterways draining to Te Waihora, and from the lake itself. Therefore, because of a <u>tangible risk of increased contamination of kai</u> a consent for the proposed activity should not be granted. Contamination of kai is in breach of sections 4.1, 4.2, and 4.3 of the co-governance agreement between SDC, Ecan, DoC and Ngai Tahu for management of Te Waihora.

Summary

Any one of the 6 scenarios listed above should stop a solar farm being sited at Brookside. As contaminants accumulate in soils, and then bioaccumulate in plants, animals, and aquatic ecosystems, the problems identified get progressively worse (i.e., there is biomagnification that causes bioaccumulation). What magnifies these issues is that all substances are "forever chemicals" that persist in the environment for decades, which means once a terrestrial or aquatic ecosystem is contaminated it remains contaminated for many, many decades. We can state unequivocally that productive lands will be perennially changed by contaminants and slowly become unproductive lands; once aquatic ecosystems are contaminated by heavy metals and PFAS they are perennially contaminated; the endangered mudfish are unlikely to survive in the waters around the proposed solar farm; once heavy metals get into the food web of terrestrial vertebrates they remain there for a long time; and once traditional kai of the local rununga is wilfully contaminated it will always be contaminated.

Recommendations:

- Solar farms should not be located on loams where leachates accumulate in soils and bioaccumulate in vegetation, fruits, and seed. Terrestrial vertebrates consuming contaminated plant matter will be affected to varying extents.
- Solar farms should be located on unproductive lands (LUC ≥4) where a permeable soil enables contaminates to be leached into the subsoil.
- Solar farms should not be located alongside waterways where heavy metals and PFAS washed off compacted soils can contaminate freshwater.
- The type of solar panel used to generate electricity in New Zealand should be vetted for environmental risks before being installed over extensive areas of cultivated land.
- Solar farms should not be located alongside places where people reside.

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Appendix 1: Test methodologies for soils.

ARL analytical research laboratories

ARL SOIL TEST METHODOLOGY - ABRIDGED

Introduction

Soil test methods generally tend to be aged especially when dates in the literature references are considered. Major changes to soil test methodology is unlikely to happen because development of a laboratory test method *per se* is not the expensive component, but the field trials involved for calibration purposes to establish meaningful guidelines based on field derived yields. More than 3000 field trials were performed on pasture by MAF and AgResearch resulting in well established guidelines for pasture production based on soil test methods used by ARL and other main stream commercial laboratories.

Changes to the methodology that may, and did happen, are instrumental of nature where advances in instrumentation resulted in simultaneous measurement of multiple elements instead of time consuming single element measurements.

Key references are shown in bold.

All soils are air dried at 38 °C and ground to pass a 2 mm screen prior to analysis.

List of methods

- Soil pH
- Olsen Phosphorus
- Soil Cations (K, Ca, Mg and Na)
- Sulphate Sulphur Analysis
- Total Extractable Sulphur (TES) and Extractable Organic Sulphur (EOS).
- Soil Cation Exchange Capacity (CEC) sometimes (incorrectly) referred to as the Effective Cation Exchange Capacity (ECEC)
- ASC or Phosphate Retention Index
- Resin Phosphorus
- Anaerobic Mineralisable Nitrogen
- Total Carbon Analysis
- Total Nitrogen by the Dumas Method
- Organic Matter
- Acid Extractable Elemental Composition of Soil (EPA)
- Reserve Potassium (TBK)
- Reserve Magnesium
- Mineral N (Ammonium-N and Nitrate-N)
- Hot water soluble Boron
- EDTA trace elements
- Chloride
- Soluble salts
- Extractable Aluminium ($CaCl_2$)

Analytical Research Laboratories

ARL analytical research laboratories

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Customer:	HAURERE FARMS LTD			**Customer No:**	60438294
	C/- M J DALLEY			**Sampled date:**	14/11/2023
	56 BUCKLEYS ROAD			**Report Issued:**	21/12/2023
	RD 2			**Samples Received:**	15/11/2023
	LEESTON 7682	**Service Person:**	Bassett S	**Order Number:**	P7174269
	03 3291695	**Name:**	Sarah Bassett		021 900266
Samples:	2	**Email:**	sarah.bassett@ravensdown.co.nz;		

60438294-P7174269

SOIL ANALYSIS

Lab Number	Sample Name	Core Depth (cm)	pH	Olsen Sol. P	Calcium	Magnesium	Potassium	Sodium	Sulphate Sulphur	Ext.Org. Sulphur
			.	ug/mL	QTU	QTU	QTU	QTU	ug/g	ug/g
2324324	Solar Panel Drip Line	15	5.9	37	14	65	12	8	26	4
2324322	No Solar Panels	15	6.6	56	14	57	32	6	6	6

Lab Number	Sample Name	Core Depth (cm)	Organic Matter	Total Nitrogen	Total Carbon	Carbon/ Nitrogen
			% w/w	% w/w	% w/w	Ratio
2324324	Solar Panel Drip Line	15	7.8	0.51	4.54	9
2324322	No Solar Panels	15	7.8	0.46	4.55	10

Lab Number	Sample Name	Core Depth (cm)	Temperature on Receipt	Potentially mineralisable N	Potentially mineralisable N	Nitrate-Nitrogen	NH4 Nitrogen	Mineral Nitrogen
			°C	mg/kg	kg/ha	mg/kg DM	mg/kg DM	mg/kg DM
2324324	Solar Panel Drip Line	15	<10	196	235	21.7	4.9	26.6
2324322	No Solar Panels	15	<10	185	228	15.5	4.7	20.2

Notes:
The PMN test is only valid for 15cm or 30cm core lengths.
It is advised that nitrogen soil samples are sent to the laboratory and received at less than 10°C to reduce mineralisation during transport. Results should be treated with caution if not <10°C

Lab Number	Sample Name	Core Depth (cm)	HWS Boron	Exch. Al
			mg/kg	mg/kg
2324324	Solar Panel Drip Line	15	2.1	<0.5
2324322	No Solar Panels	15	1.8	<0.5

Lab Number	Sample Name	Core Depth (cm)	EDTA Cobalt	EDTA Mang.	EDTA Iron	EDTA Copper	EDTA Zinc
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
2324324	Solar Panel Drip Line	15	1.7	274	2040	4.4	12.7
2324322	No Solar Panels	15	1.5	241	1214	3.6	12.2

Lab Number	Sample Name	Core Depth (cm)	EPA-ext Arsenic	EPA-ext Cadmium	EPA-ext Chromium	EPA-ext Lead	EPA-ext Mercury	EPA-ext Nickel	EPA-ext Copper	EPA-ext Zinc
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
2324324	Solar Panel Drip Line	15	5.2	0.22	19.7	20	< 0.12	10.1	13	77
2324322	No Solar Panels	15	4.1	0.17	18.6	16.4	< 0.12	9.7	13	74

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Certificate of Analysis

Client:	Analytical Research Laboratories	**Lab No:**	3463643 SPv1
Contact:	Laura Viljoen	**Date Received:**	12-Feb-2024
	C/- Analytical Research Laboratories	**Date Reported:**	15-Feb-2024
	PO Box 989	**Quote No:**	
	Napier 4140	**Order No:**	384981
		Client Reference:	
		Submitted By:	Laura Viljoen

Sample Type: Soil

Sample Name:		2335785 Control 30-Jan-2024	2335786 Test 30-Jan-2024
Lab Number:		3463643.1	3463643.2
Total Recoverable Aluminium	mg/kg dry wt	15,200	16,000

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Labs, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-2
Total Recoverable Aluminium	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	50 mg/kg dry wt	1-2

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 13-Feb-2024 and 15-Feb-2024. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Appendix 3

Soil Detail

Report prepared for:
Pest-Tech
Ray Henderson
233 Branch Drain Road
Leeston, undefined 7682

For interpretation of this report, please contact your local Soil Steward or the lab.

Report Sent: 01/02/2024
Sample #: 05-9294
Unique ID: Test
Plant: Pasture
Season: summer
Invoice Number: 588
Sample Received: 27/01/2024

Soil Foodweb NZ
107 Argelins Road
Hanmer Springs, North Canterbury 7334
02108214323
info@soilfoodweb.co.nz
http://www.soilfoodweb.co.nz

Assay Name	Result	Units	Range	Commentary
Organism Biomass Data				
Dry Weights	0.79	N/A	0.45 to 0.85	Within normal moisture levels indicating organic matter at reasonable levels, however organic matter must come in contact with active microbes to be converted into valuable, stable humus.
Active Fungi	4.00	µg/g	> 30	Fungal activity low. Soil's fungal food resources probably too low. Additions of fungal foods with other inputs should help to lift levels i.e; good quality humates, fish hydrolysates, fungal dominant compost etc.
Total Fungi	140.43	µg/g	> 300	Low total fungal biomass, foods and biology may be required. Increasing fungal activity builds fungal biomass improving soil structure nutrient cycling and disease suppression. - Fungal diversity appears low. Only small and medium length hyphae
Hyphal Diameter	2.75	µm	> 2.5	
Active Bacteria	11.77	µg/g	> 30	Bacterial activity low. Soil's bacterial food resources probably low. Additions of seaweed type products should help sustainably lift active bacterial levels.
Total Bacteria	377.79	µg/g	> 300	Good total bacterial biomass. However Bacteria are out competing fungal biomass.Protozoa feed on the bacteria so activity levels need to increase to offset this.
Actinobacteria	0.00	µg/g	< 20	
Organism Biomass Ratios				
TF:TB	0.37		0.85 to 1.45	Too bacterial for Pasture. Need to build fungal biomass closer to desired range while maintaining bacterial biomass to achieve a ratio closer to 1.0
AF:TF	0.03		> 0.1	The overall percentage of active fungal biomass is too low.
AB:TB	0.03		> 0.1	The overall percentage of active bacteria is too low
AF:AB	0.34		0.85 to 1.45	Bacterial dominated soil, becoming more bacterial with time. Not a desirable trend in this instance.
Protozoa (Protists)				
Flagellates	579410.84	#/g	> 10000	Lacking species diversity. Flagellates at excellent levels. Amoebae at low levels but Nutrients are being recycled at excellent levels
Amoebae	174.85	#/g	> 10000	
Ciliates	578.66	#/g	< 5796	
Nitrogen Cycling Potential	336+	kg/ha		Nitrogen levels dependent on plant needs. Estimated availability over a 3 month period.
Nematodes				
Nematodes	Not Ordered	#/g	> 10	
Bacterial		#/g		
Fungal		#/g		
Fungal/Root		#/g		
Predatory		#/g		
Root		#/g		
Mycorrhizal Fungi				
ENDO	22.00	%	> 40	Low colonization, fungal foods may be required to improve vigour and lift Mycorrhiza levels..

Soil Detail

Report prepared for:
Pest-Tech
Ray Henderson
233 Branch Drain Road
Leeston, undefined 7682

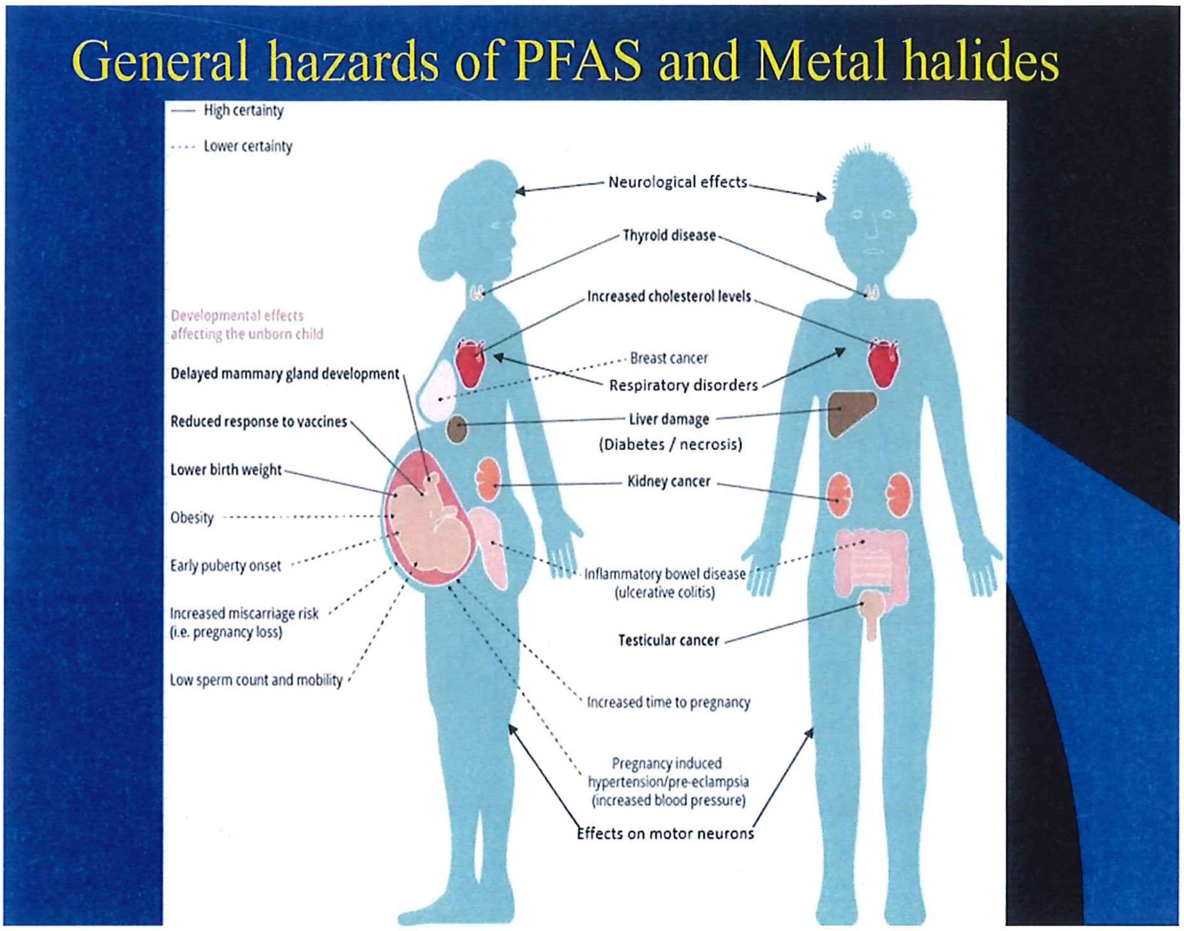
For interpretation of this report, please contact your local Soil Steward or the lab.

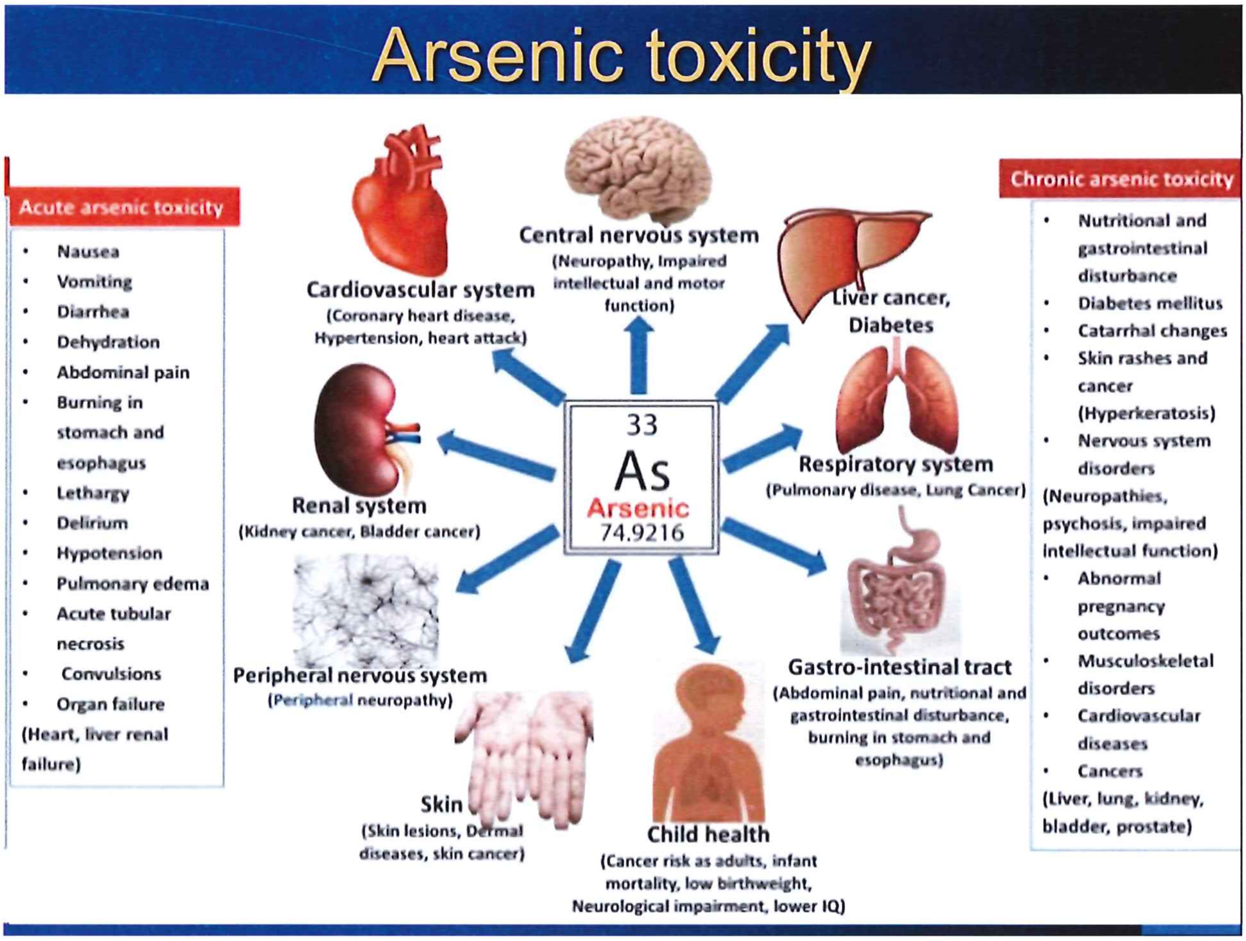
Report Sent:	01/02/2024
Sample #	05-9295
Unique ID:	Control
Plant:	Pasture
Season:	summer
Invoice Number:	588
Sample Received:	27/01/2024

Soil Foodweb NZ
107 Argelins Road
Hanmer Springs, North Canterbury 7334
02108214323
info@soilfoodweb.co.nz
http://www.soilfoodweb.co.nz

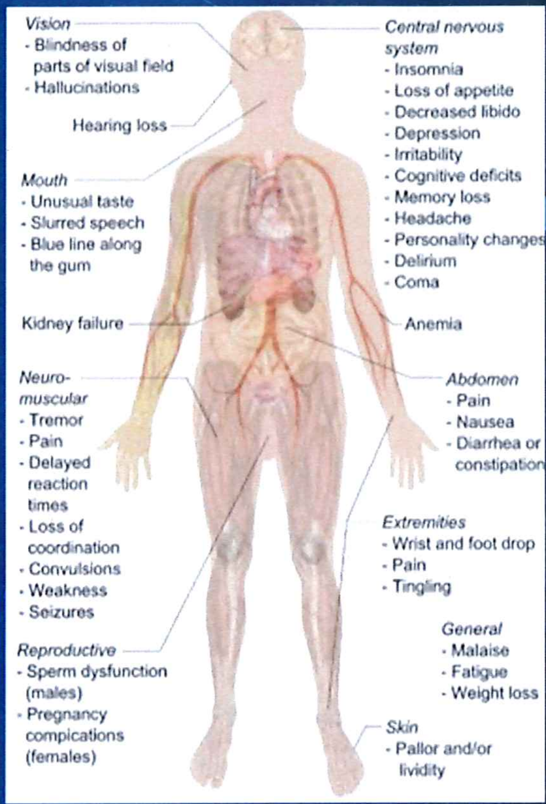
Assay Name	Result	Units	Range	Commentary
			Organism Biomass Data	
Dry Weights	0.71	N/A	0.45 to 0.85	Within normal moisture levels indicating organic matter at reasonable levels, however organic matter must come in contact with active microbes to be converted into valuable, stable humus.
Active Fungi	8.31	µg/g	> 30	Fungal activity low. Soil's fungal food resources probably too low. Additions of fungal foods with other inputs should help to lift levels i.e; good quality humates, fish hydrolysates, fungal dominant compost etc.
Total Fungi	297.52	µg/g	> 300	Low total fungal biomass, foods and biology may be required. Feed as above. Increasing fungal activity builds fungal biomass improving soil structure, disease suppression and nutrient cycling i.e; Calcium - Fungal diversity at adequate levels. Some large and healthy hyphae evident
Hyphal Diameter	3.00	µm	> 2.5	
Active Bacteria	13.70	µg/g	> 30	Bacterial activity low. Soil's bacterial food resources probably low. Additions of seaweed type products should help sustainably lift active bacterial levels.
Total Bacteria	453.54	µg/g	> 300	Good total bacterial biomass. Indicates bacterial diversity.
Actinobacteria	0.00	µg/g	< 20	
			Organism Biomass Ratios	
TF:TB	0.66		0.85 to 1.45	Too bacterial for Pasture. Need to build fungal biomass closer to desired range while maintaining bacterial biomass to achieve a ratio closer to 1.0
AF:TF	0.03		> 0.1	The overall percentage of active fungal biomass is too low.
AB:TB	0.03		> 0.1	The overall percentage of active bacteria is too low
AF:AB	0.61		0.85 to 1.45	Bacterial dominated soil, becoming more bacterial with time. Not a desirable trend in this instance.
			Protozoa (Protists)	
Flagellates	647102.85	#/g	> 10000	Flagellates at very good levels. Amoebae low, however some excellent nutrient cycling potential by these bacterial eating predators. High ciliate numbers indicate possible anaerobic conditions.
Amoebae	1900.85	#/g	> 10000	
Ciliates	8083.87	#/g	< 6490	
Nitrogen Cycling Potential	336+	kg/ha		Nitrogen levels dependent on plant needs. Estimated availability over a 3 month period.
			Nematodes	
Nematodes	Not Ordered	#/g	> 10	
Bacterial		#/g		
Fungal		#/g		
Fungal/Root		#/g		
Predatory		#/g		
Root		#/g		
			Mycorrhizal Fungi	
ENDO	54.00	%	> 40	Normal colonization. Some grass system can get to 65 to 75% colonisation

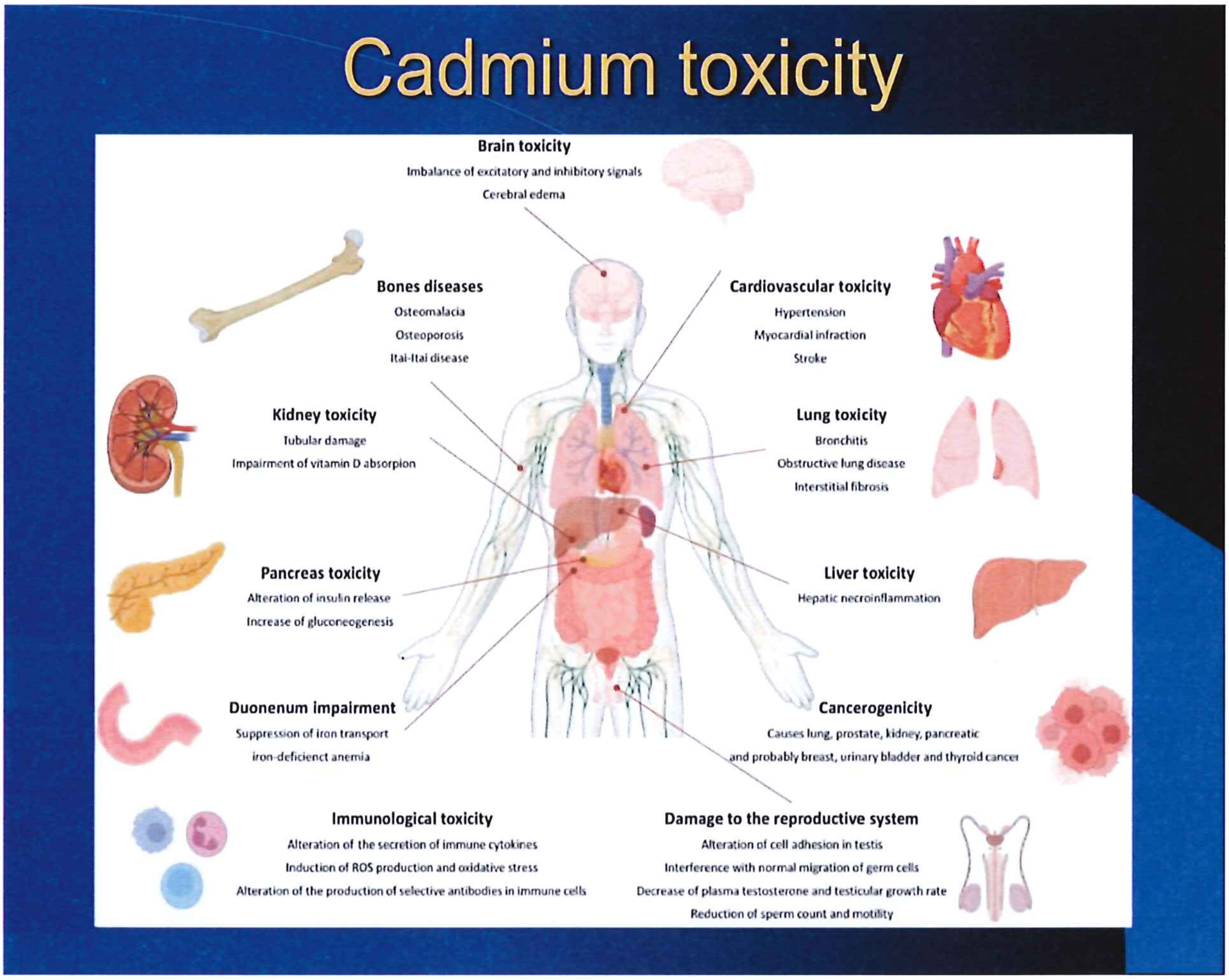
Appendix 4. **Health hazards associated with heavy metals and PFAS known to be leached from panels at Brookside.**

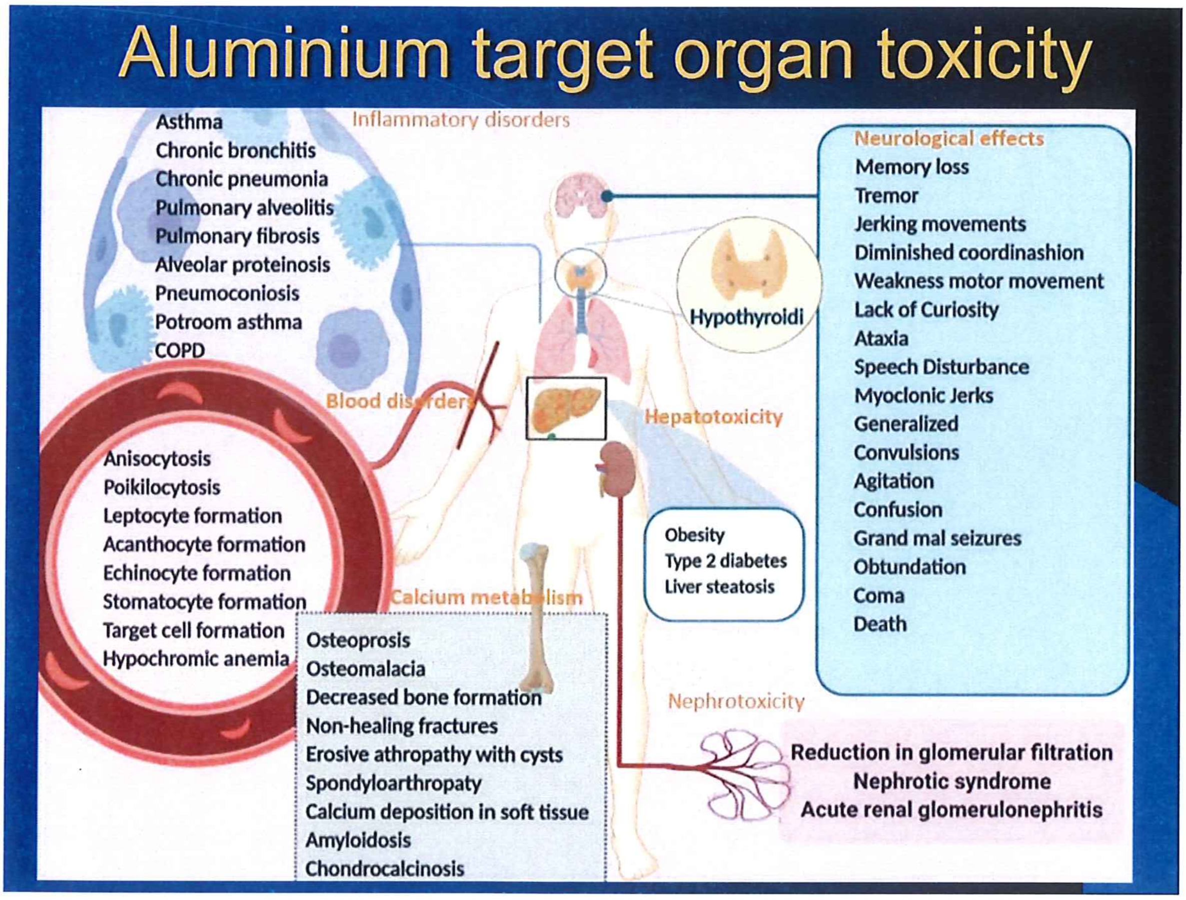



Arsenic toxicity
Acute arsenic toxicity
• Nausea
• Vomiting
• Diarrhea
• Dehydration
• Abdominal pain
• Burning in stomach and esophagus
• Lethargy
• Delirium
• Hypotension
• Pulmonary edema
• Acute tubular necrosis
• Convulsions
• Organ failure
(Heart, liver renal failure)
Cardiovascular system
(Coronary heart disease, Hypertension, heart attack)
Central nervous system
(Neuropathy, Impaired intellectual and motor function)
Liver cancer, Diabetes
Renal system
(Kidney cancer, Bladder cancer)
33
As
Arsenic
74.9216
Respiratory system
(Pulmonary disease, Lung Cancer)
Peripheral nervous system
(Peripheral neuropathy)
Gastro-intestinal tract
(Abdominal pain, nutritional and gastrointestinal disturbance, burning in stomach and esophagus)
Skin
(Skin lesions, Dermal diseases, skin cancer)
Child health
(Cancer risk as adults, infant mortality, low birthweight, Neurological impairment, lower IQ)
Chronic arsenic toxicity
• Nutritional and gastrointestinal disturbance
• Diabetes mellitus
• Catarrhal changes
• Skin rashes and cancer (Hyperkeratosis)
• Nervous system disorders
(Neuropathies, psychosis, impaired intellectual function)
• Abnormal pregnancy outcomes
• Musculoskeletal disorders
• Cardiovascular diseases
• Cancers
(Liver, lung, kidney, bladder, prostate)

Lead target organ toxicity




Cadmium toxicity
Brain toxicity
Imbalance of excitatory and inhibitory signals
Cerebral edema
Bones diseases
Osteomalacia
Osteoporosis
Itai-Itai disease
Cardiovascular toxicity
Hypertension
Myocardial infraction
Stroke
Kidney toxicity
Tubular damage
Impairment of vitamin D absorpion
Lung toxicity
Bronchitis
Obstructive lung disease
Interstitial fibrosis
Pancreas toxicity
Alteration of insulin release
Increase of gluconeogenesis
Liver toxicity
Hepatic necroinflammation
Duonenum impairment
Suppression of iron transport
iron-deficienct anemia
Cancerogenicity
Causes lung, prostate, kidney, pancreatic
and probably breast, urinary bladder and thyroid cancer
Immunological toxicity
Alteration of the secretion of immune cytokines
Induction of ROS production and oxidative stress
Alteration of the production of selective antibodies in immune cells
Damage to the reproductive system
Alteration of cell adhesion in testis
Interference with normal migration of germ cells
Decrease of plasma testosterone and testicular growth rate
Reduction of sperm count and motility



Note: exposure to aluminium also reduces the efficacy of vaccines on children.