



Northland's Landscape Driven Erosion Map: A Resource for Decision-Makers and Communities

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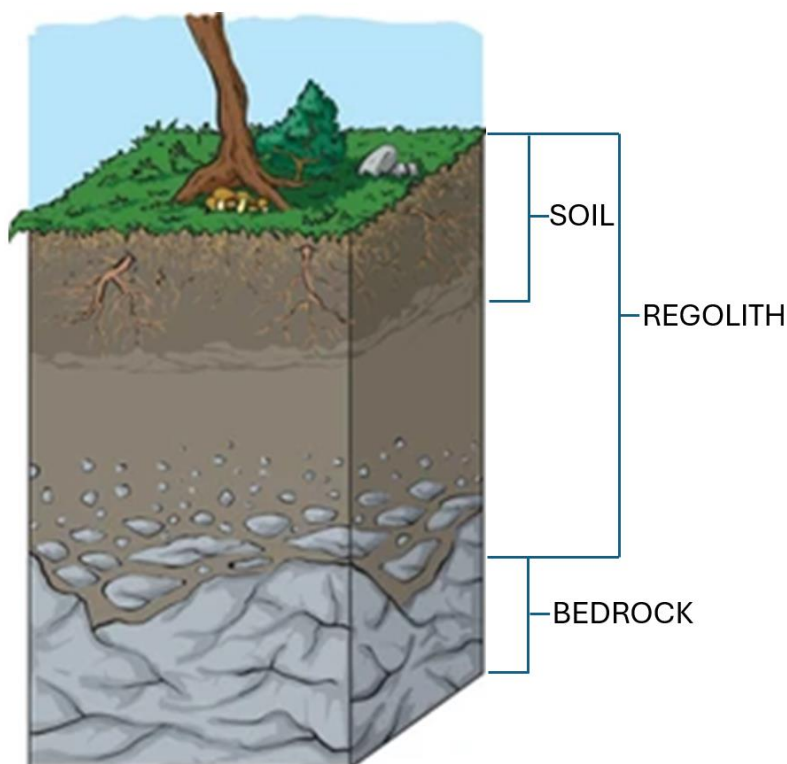
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Community Summary

Across Northland, erosion and land movement—like slips, slumps, and gullying—are common features of the landscape. These processes are not random or new. They are long-standing expressions of the land’s natural structure, shaped by geological forces over millions of years.

Geology and soil together shape how the land behaves. Geology determines the arrangement of rock layers, the presence of ancient faults and folds, and the type of material that sits beneath the soil (called regolith). These deep features affect whether the land holds together or breaks apart when wet or disturbed. But geology also sets the overall shape of the landscape—including valleys, ridges, and steepness—and this in turn influences rainfall, sun exposure, and how soil forms. The types of rocks and sediments present also affect which plants and organisms can grow. In this way, geology is the foundation of the land's structure and of the soils that sit on top of it. When we talk about the land’s susceptibility to erosion and land movement, it is this combination of underlying geology and overlying soils that sets the scene—not just the steepness of the land.



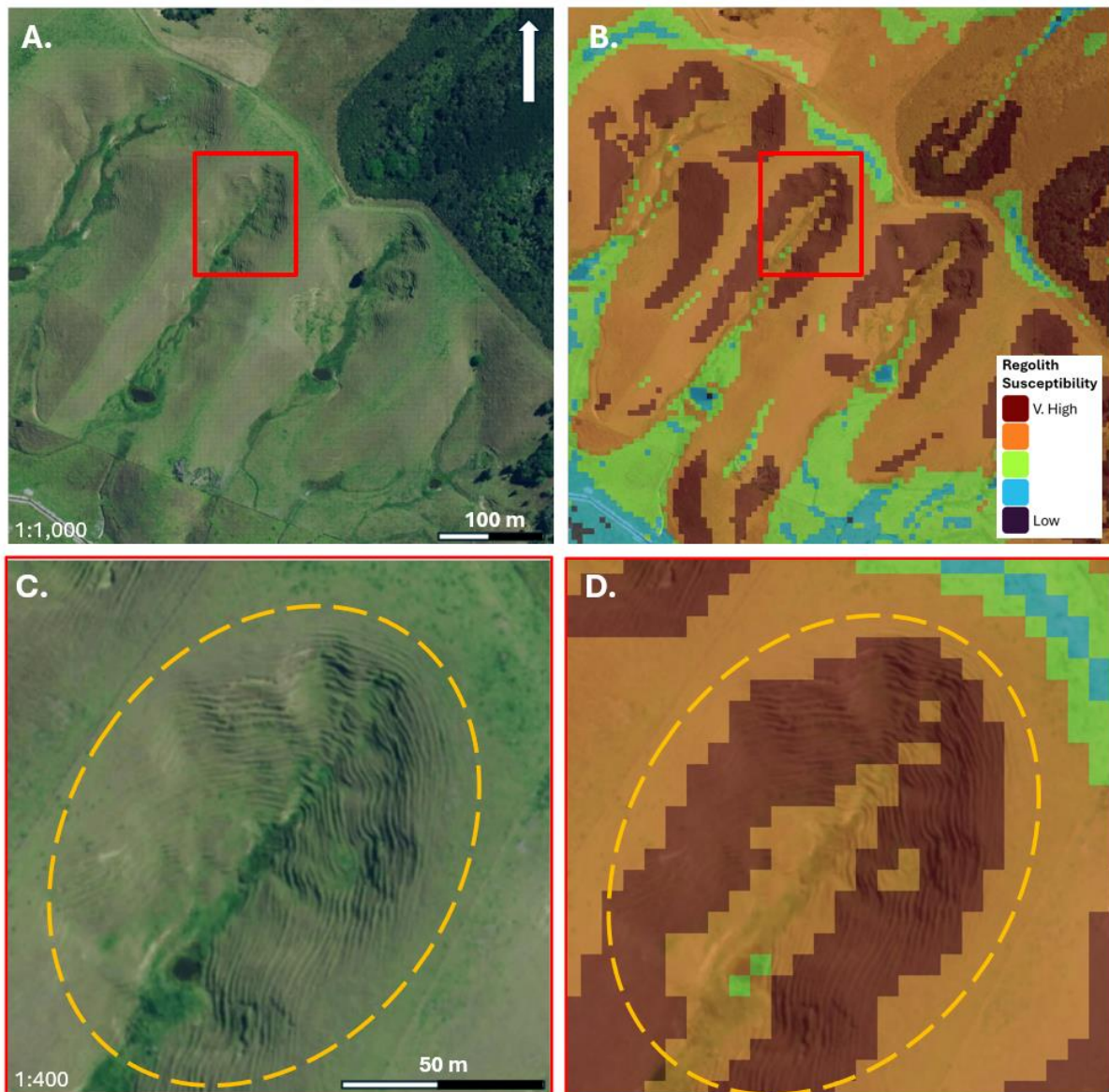
A diagram of the regolith, which includes the soil and weathered materials overlying unweathered bedrock. The depth of the regolith varies from place to place, including the thickness of the soil component.

The underlying rock layers, ancient faults and folds, and the way materials have weathered and broken down over time all combine to set how stable or fragile the regolith is. These deep patterns govern how the regolith forms, how water moves, and how the terrain responds when disturbed.

Land use—whether for infrastructure, forestry, horticulture, or development—can add pressure, but it doesn’t define the land’s inherent sensitivity. That sensitivity was established long ago. What land use often does is expose or reveal that natural vulnerability through disturbance. In other words, land use doesn't cause susceptibility; it interacts with it. Understanding that sensitivity is essential for knowing where erosion is more likely and what kinds of actions will be most effective in reducing it.

To support this understanding, Northland Regional Council has developed S-PAL—the Sediment–Process Attribute Layer. This tool identifies which parts of the landscape are naturally more or less

prone to erosion and instability. It does this using direct measurements of the land itself, not assumptions about land use or vegetation cover.



The S-PAL Regolith Susceptibility Classification. A. Aerial photograph of narrow incised gullies. B. S-PAL Regolith Susceptibility Classification. C. Close-up of an area of gully head and wall erosion (red rectangle insert). D. Close-up of S-PAL Regolith Susceptibility Classification (red rectangle insert).

The S-PAL Classification works at multiple scales, from regional to property, and property to paddock scale. It is entirely independent of land use. It doesn't include whether the land is farmed, forested, developed, or in bush. Instead, it focuses on the land's natural structure—the characteristics that remain, regardless of how the land is being used.

To build this picture, two powerful modern technologies were used:

- **LiDAR (1-metre resolution)**, which uses lasers from aircraft to create detailed 3D maps of the land's shape (**topography**, e.g., slope, aspect)—even under dense vegetation.
- **Regional radiometric survey (50-metre resolution)**, which works like a chemical scan of the ground. It detects natural signals from minerals in the earth, helping us understand the

composition of the loose layer of soil and weathered sediments that overlie deeper bedrock and how weathered or disturbed the surface materials are.

Both LiDAR and radiometric survey are measurement tools that reveal the natural grain of the landscape. When combined they can detect variation in regolith properties from broad regional patterns down to the scale of individual paddocks (25 m or 1:200). Together, they provide high-resolution data across the entire region, offering a more detailed and continuous view of Northland's landforms than has ever been possible before.

Existing soil and geological maps—such as the 1:63,000 soil surveys (Fundamental Soil Layer, FSL; 1:63,000) and the 1:250,000 Q-MAP geological series—remain important resources for understanding the broad structure and character of the landscape. These maps provide a regional-scale view of how different materials are distributed and have long been foundational in land management, planning, and research.

However, the landscape is seldom so sharply or crisply bounded as our regional scale soil and geological maps suggest. Rather, regolith properties often change across short distances on a hill slope, and zones of ancient faults, rock layering, and other weaknesses can occur between more stable areas. These finer-scale variations are often where erosion initiates, but they can be difficult to resolve using regional mapping units alone.

Rather than redrawing geological or soil boundaries, S-PAL highlights where the physical conditions on the ground may increase the likelihood of erosion—even within a single mapped soil or rock unit. This helps support more focused responses, such as identifying which parts of a hillside might need stabilisation, or where to target erosion control work to be most effective.

1 Introduction

To manage **erosion** effectively in Northland, it's important to understand that soil loss isn't caused by just one thing. It often results from both what happens on the surface—like water running off wet soils during heavy rain—and what's going on beneath the surface. Deeper conditions in the landscape can make land more prone to slipping or breaking apart, especially when saturated with water. If we only focus on what's happening within the soil, we miss a big part of the picture.

The layer that plays the biggest role here is the **regolith**¹—a blanket of loose material that sits above the solid rock underneath (Fig. 1). It includes the soil, but also underlying layers of weathered rock and sediment that have built up over thousands or even millions of years. This deeper layer plays a key role in shaping how the land behaves. It influences whether water soaks in or runs off, how strongly the land holds together, and how it responds when it's under stress—like during heavy rain, land development, or just the pull of gravity.

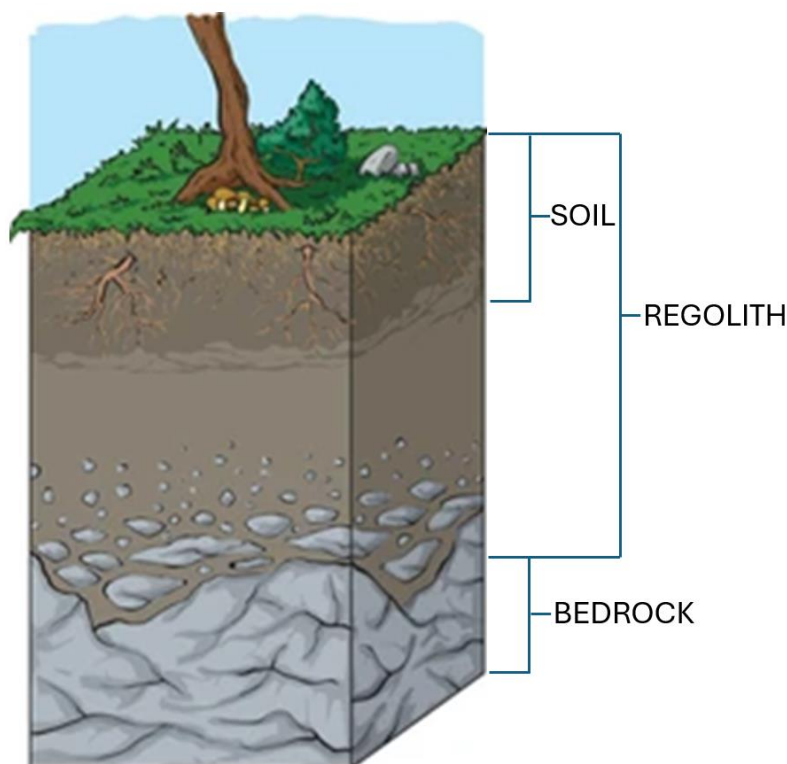


Figure 1 A diagram of the regolith.

The regolith includes the soil and weathered materials overlying unweathered bedrock. The depth of the regolith varies from place to place, including the thickness of the soil component.

Across Northland, the regolith varies a lot because the rocks and sediments it has formed in are so varied. Some areas sit on hard volcanic rock (e.g., Tangihua Basalts), others on softer materials like **mudstones** and **sandstones** (e.g., Punakitere sandstone and mudstone), swamp, or even ancient coastal sediments formed when the sea level was higher. These differences affect how stable the regolith is, how much water it holds, and how likely it is to break down or erode. In many settings, erosion is triggered when the contact between the regolith and deeper **bedrock** fails or slips. During such an event, the soil, subsoil, and the deeper layers of regolith materials are also lost, but not through **runoff** but due to deeper controls, some of which are very much beyond our control.

¹ Terms in **bold** are defined in the Technical Appendix.

That's why the **Northland Regional Council (NRC)** developed the **Sediment–Process Attribute Layer (S-PAL)**. NRC wanted to take a step back and understand the bigger picture—looking not just at the surface soil zone, but also at the deeper regolith. The goal was to explore why some parts of Northland experience high levels of sediment loss, even where soils themselves may not seem particularly erosion-prone. S-PAL is a region-wide tool that classifies the different types of regolith across Northland to help explain these patterns more clearly. It is built entirely upon modern, high-resolution datasets that provide unique insights into the type and behaviour of Northland's regolith. To create S-PAL, NRC used two key datasets:

- **LiDAR Data (1-metre resolution):** High-resolution 3D scans that map land shape, slope, and surface roughness.
- **Radiometric Data (50-metre resolution):** Scans of natural radiation emitted from the ground, revealing the chemistry, texture, age, and other features of the regolith.

By combining these two datasets and applying statistical methods, Northland's regolith was grouped objectively into categories—letting the data reveal the patterns. Think of it like building a family tree using DNA testing—but for the land. Parts of Northland that shared similar topography, geology, regolith thickness, texture (e.g., sand vs clay), and age (degree of weathering) were grouped together. The statistical grouping revealed three dominant layers or patterns, subdividing the landscape into:

- **Four Domains:** Broad groups based on overall landform, such as steep hills or flat plains.
- **Twelve Families:** These are based on the type of underlying rock or sediment, like **basalt** or sandstone.
- **Thirty-five Siblings:** These represent local variations in how thick, weathered (old), or textured the regolith is.

This classification is not about guessing. It's based on real, measurable features of the land—grouping areas that share similar landscape shapes, rock and sediment types, and properties like texture (e.g., sand vs clay), depth (how thick the regolith is), and weathering (how old the regolith is). The result is a kind of family tree for Northland's regolith. For example, the steep, rugged Tangihua Ranges and the more rolling limestone hill country fall into different Domains, each with their own distinctive Families and Siblings. That makes sense, given how different the landforms and underlying materials are. While this classification doesn't directly tell us which areas are currently eroding, it gives us the relational structure based on actual measurements of the Northland landscape to begin answering that question—based on how similar or different one part of the landscape is from another.

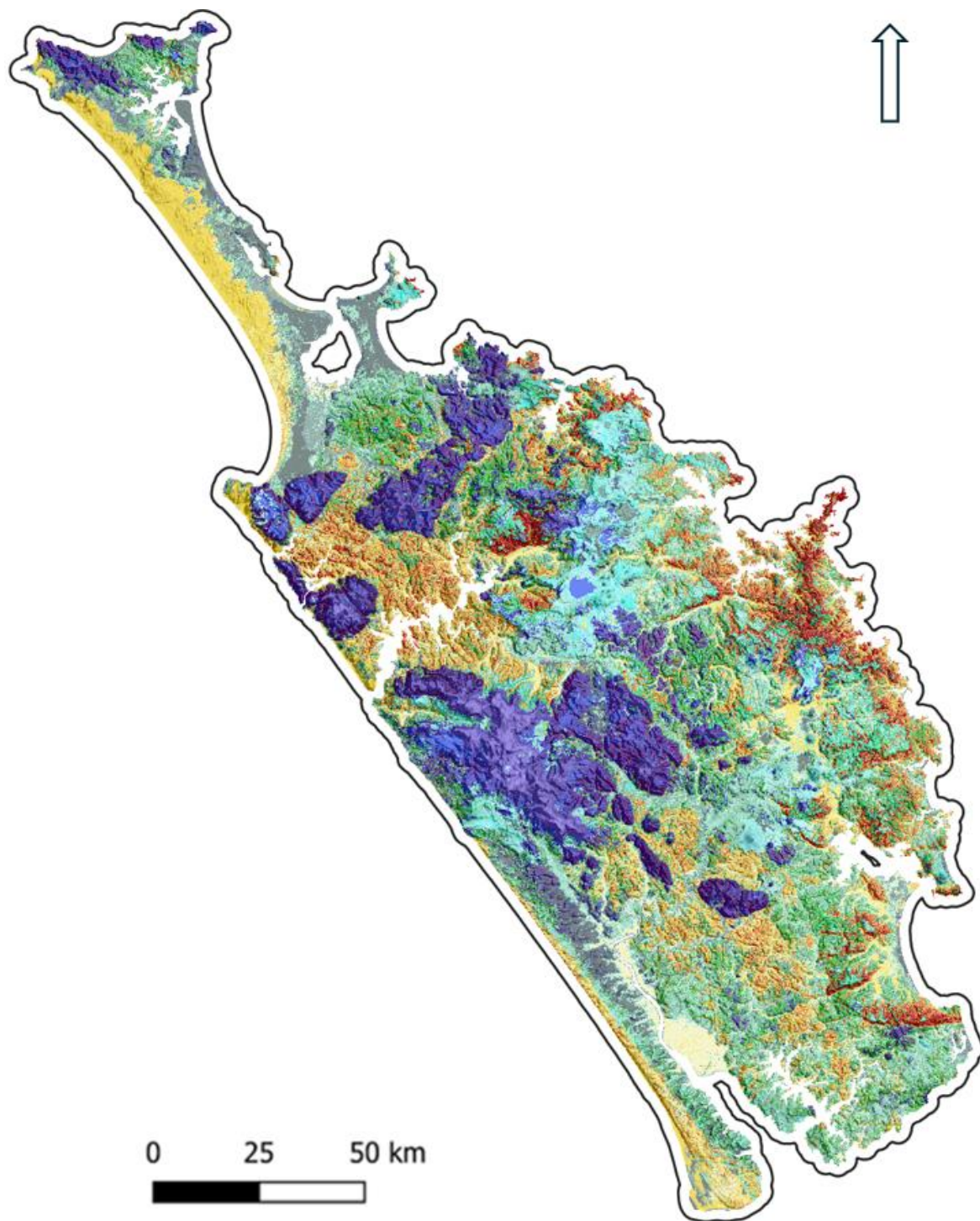


Figure 2 The S-PAL Regolith Classification.

The S-PAL Regolith Classification groups parts of Northland's landscape according to shared physical traits—such as landform shape (topography), underlying geology, surface texture (e.g., silt vs clay), regolith thickness, and age (degree of weathering). It's a bit like constructing a family tree for the land: areas are grouped not just by how they look, but by their DNA.

The next step was to understand how active the regolith of each domain, family, and sibling is—how recently it has been active. To do this, NRC looked again at the mineral signals provided by the radiometric scanning, searching for areas where the regolith has changed compared to what would normally be expected. These differences tell us where the land has been actively eroding or where it has remained stable. In addition to the activity of the regolith, NRC commissioned the development of a new soil runoff layer.

With this information, each of the approximately 7.3 million regolith units were ranked—from those more likely to erode to those that appear more stable (Fig. 3). Because S-PAL is built from measured characteristics of the regolith and its activity, it also helps us consider how erosion may relate to deeper geological features—such as **faults** (large underground breaks), **folds** (bends in rock layers), and **stratigraphy** (the natural layering of different rock types).

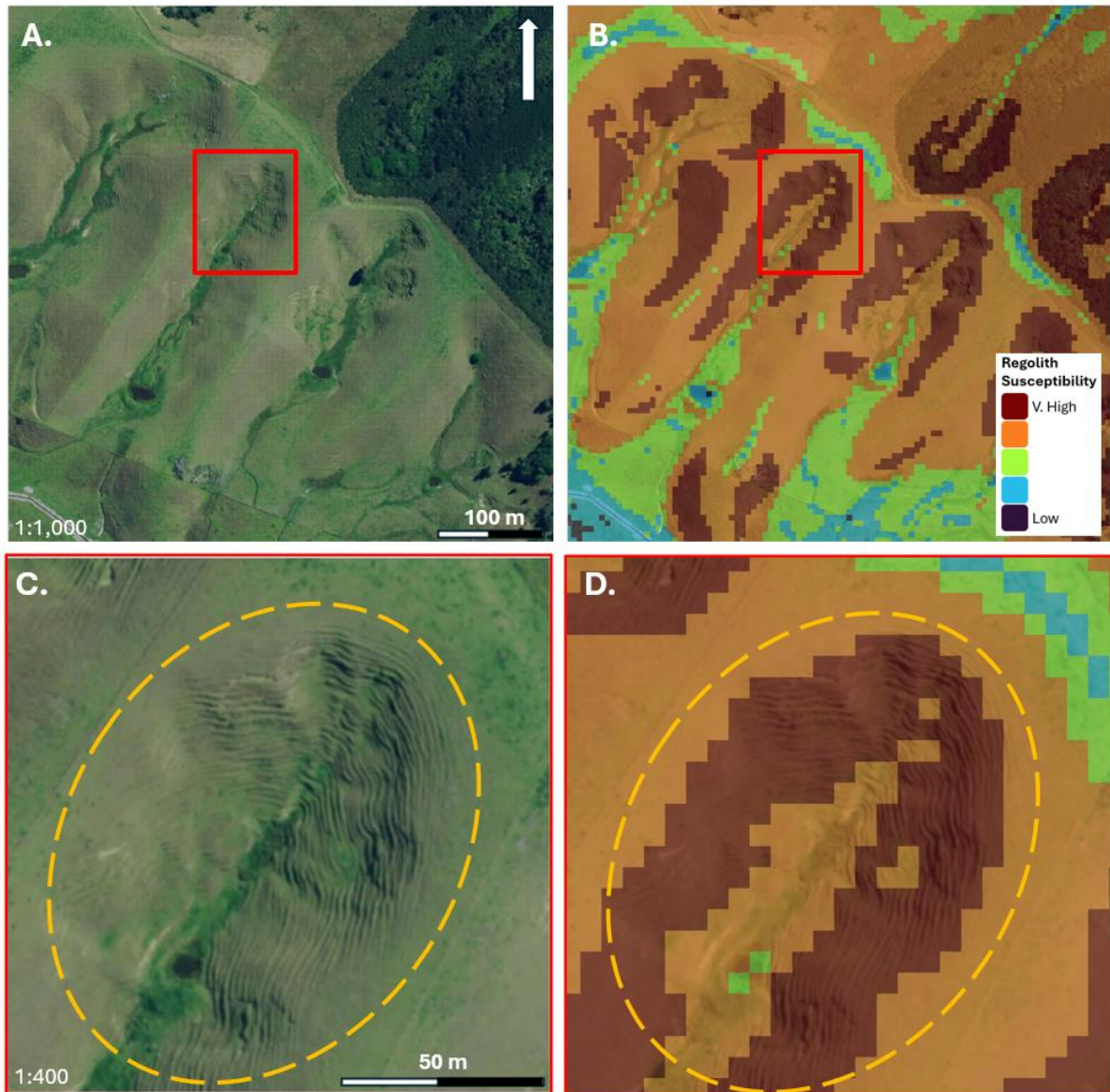


Figure 3 The S-PAL Regolith Susceptibility Classification.

A. Aerial photography of narrow incised gullies. B. S-PAL Regolith Susceptibility Classification. C. Close-up of an area of gully head and wall erosion (red rectangle insert). D. Close-up of S-PAL Regolith Susceptibility Classification (red rectangle insert).

These are long-standing features of Northland's geology that influence how the landscape behaves, even if we don't see them directly. The S-PAL results suggest there are consistent links between these deeper structures and how disturbed or settled the regolith appears to be—patterns that align with geological expectations, but are now more clearly represented in a landscape-wide classification. This two-step approach—first understanding what the land is made of, then seeing how it behaves—gives us powerful insights. It helps explain why, despite best efforts of land users, some areas (e.g., adjacent to an ancient fault) are so unstable.

S-PAL doesn't replace **soil maps** or geological maps. It works alongside them, giving landowners, councils, and communities a clearer, more detailed view of how the land works beneath the surface. And with that knowledge, we can make smarter, more targeted decisions to protect farms, roads, waterways, and communities across Northland.

2 Northland's Unique Landscape

Northland's landscape is unlike anywhere else in Aotearoa. Its distinct combination of subtropical climate, ancient geology, and land use history makes it especially sensitive to land instability—manifesting as both **erosion** (the gradual wearing away of soil) and **mass wasting (sudden slope failures)** like slips and **landslides**). These processes contribute to sediment loss and landscape change, and are heavily influenced by rainfall, geology, and how the land is used.

Located in the far north of the country, Northland has a mild, humid climate with warm, wet summers and mild winters. Rainfall is plentiful throughout the year, often arriving in short, intense bursts during storms. In many areas—especially along the coast and in exposed hill country—strong winds and extreme weather are common (Chappell, 2013). These climatic conditions, combined with deeply weathered geology, create ideal conditions for erosion and mass wasting.

Geologically, Northland is one of Aotearoa New Zealand's oldest and most complex regions. Unlike many other areas, it hasn't been heavily shaped by glaciers or covered in widespread volcanic ash. Instead, it has developed over tens of millions of years, preserving an ancient landscape that has been deeply weathered and slowly folded and faulted. A key feature of this complexity is the **Northland Allochthon**—a vast stack of older rocks, originally formed in the ocean, that were pushed over younger layers during major earth movements around the Early Miocene (about 23–16 million years ago; Fig. 4).

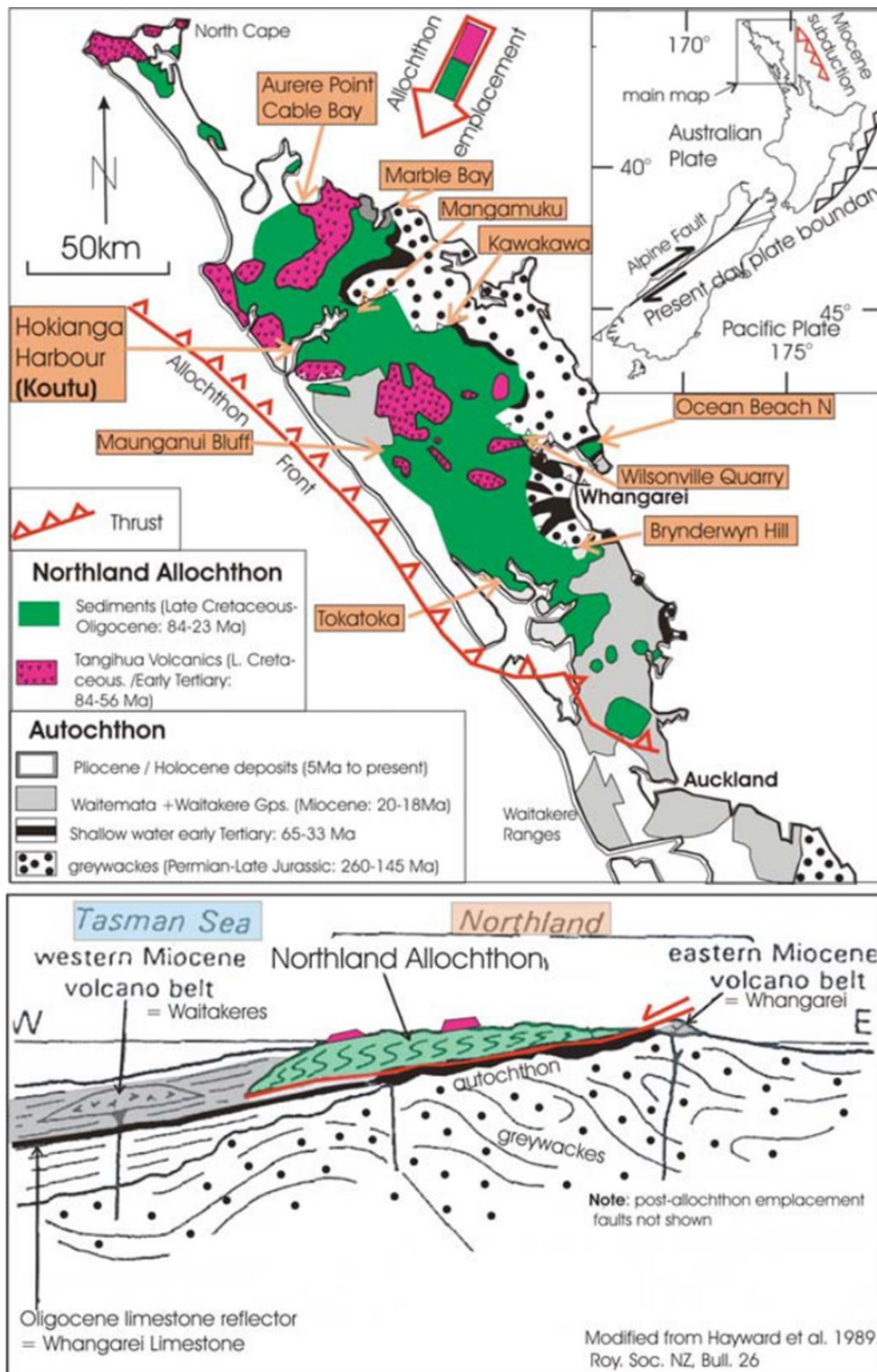


Figure 4 Simplified geology of Northland (Hayward et al. 1989).

These thrust sheets include soft marine sedimentary rocks like mudstones and sandstones, and jumbled, broken-up zones called **mélanges**, where rock types are chaotically mixed. Mixed among these weaker materials are much harder volcanic rocks, such as the Tangihua Volcanics and younger **basalt** flows like the Kerikeri and Waipoua Basalts.

This close-up pattern of weak and strong rocks, crossed by many old fault zones and contacts between very different rock types (e.g., soft sediments vs hard volcanics), creates a landscape full of contrasts (Fig. 5). The boundaries between the jumble of rocks mark areas of increased weakness or instability in the landscape. As a result, Northland's landforms are not just shaped by surface slope or soil type—they reflect the deep **geological structures** beneath, which continue to influence how erosion and land movement happen today.

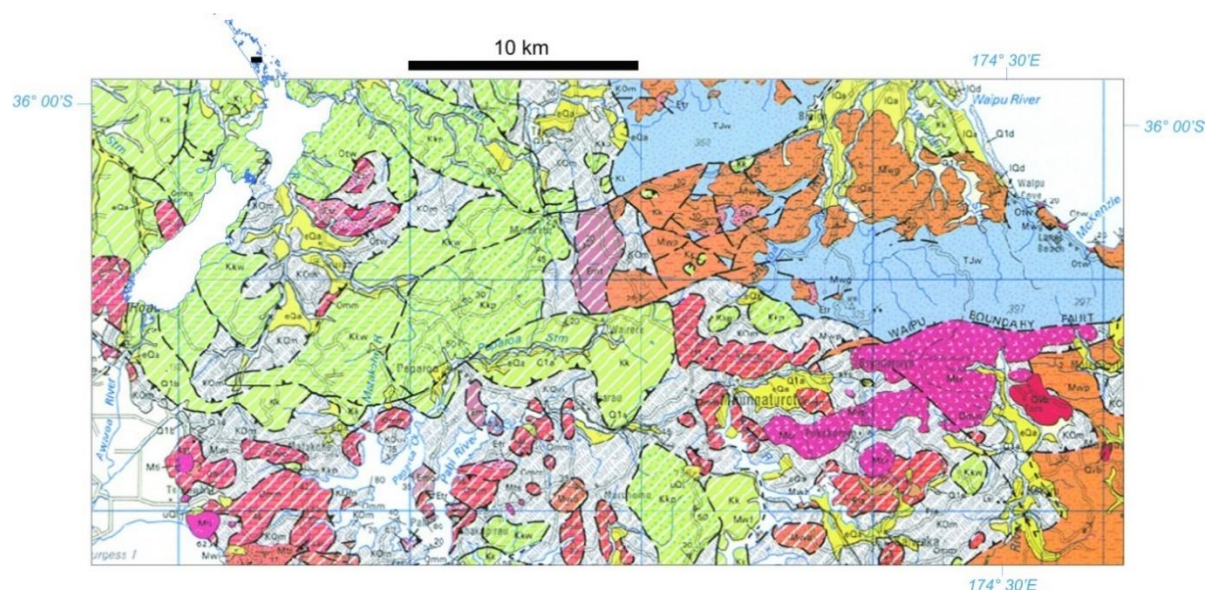


Figure 5 Map of southern Northland.

This map of southern Northland shows a complex patchwork of rock types and geological structures (Q-MAP, 1:250,000; Rattenbury & Isaac, 2012). The striped areas mark parts of the Northland Allochthon—older rocks that were pushed over younger layers along ancient, gently sloping fault lines. These movements have shuffled the original rock layers, especially in the south, where the geology becomes more jumbled and forms a mixed-up blend of rock types known as ‘mélange’ (shown in grey). The dashed black lines identify the large number of ancient fault zones.

Northland's soils reflect this history. They are some of the oldest and most deeply weathered in the country. But surface erosion of the soil is only part of the picture. Instability is also driven by the structure and behaviour of the sediments and weathered rock that lie beneath the soil—including deep-seated weaknesses that lead to surface instabilities. In many areas, it is not what's visible at the surface, but what lies beneath that determines how the land behaves.

Human activities—particularly historic, widespread forest clearance and the introduction of livestock, roading, and urban development in the last 150 years—have significantly increased the frequency and severity of erosion and mass wasting.

Today, the region's natural **susceptibility** to both erosion and mass wasting continues to be further amplified by:

- Heavy storm events, wetter-than-normal followed by drier-than-normal conditions
- Land uses that disturb or change the character of the upper few metres of the land surface including changes that influence how water moves across or through the land
- Land development and earthworks, which can disturb already fragile slopes

However, land instability is not uniform across the region. It varies depending on local geology, soil type, terrain steepness, and land use history. Understanding where and why erosion and mass wasting occur is critical for protecting productive land, infrastructure, and water quality. In naturally susceptible areas, large volumes of fine material from the regolith—including not just soil but deeper weathered materials—can be carried into streams, rivers, and estuaries. When this material is made up of fine silts and clays, it can harm aquatic ecosystems and reduce the capacity and function of natural **drainage systems**.

2.1 Geological Settings That Influence Erosion

Northland's landforms have developed through a complex geological history, influenced by the movement of tectonic plates, volcanic activity, and the slow weathering of ancient rock over millions of years.

Over time, different types of rock have been squeezed, faulted, and folded, ending up arranged in ways that create instability—especially where hard and soft rock layers are stacked (stratigraphy) or smashed together along **fault zones**. In addition to instability, these natural processes often create pathways for water to move through the rock layers, weakening them further. As a result, four broad geological settings occur across Northland, three of which contribute significantly to erosion and slope instability.

2.1.1 Fault Zones

Northland is criss-crossed by a myriad of complex and ancient fault lines (Fig. 5). Where strong volcanic rocks (like basalt) lie directly against weaker sedimentary rocks (such as sandstone or mudstone), fault lines create natural zones of weakness. Even when these faults are no longer active, the contact zones between the rock types are often steep, unstable, and prone to erosion and landslides—sometimes extending up to 8 km from the fault itself. A clear example is found where the weak Punakitere sandstone and mudstone—a widespread rock type—is crushed up against the strong volcanic rocks of the Tangihua Ranges, leading to widespread instability at the zone of contact. It's a bit like pressing a steel ram against a block of timber—any movement crushes the softer material (the sandstone or mudstone), making it more prone to failure. Northland has a large number of ancient fault and fold zones that add to its natural instability, many of which are key areas of instability identified by the S-PAL.

2.1.2 Layered Rock (Stratigraphic) Instability

In some areas, hard volcanic rocks like basalt sit on top of soft, clay-rich mudstones, as seen wherever the flood basalts of the Waipoua Basalts and Kerikeri Volcanic Group occur. These more recent lavas, broadly similar to the Hawaiian volcanoes, erupted through the weak sedimentary rocks and flowed across the top of them, forming a hard carapace or layer—a bit like icing on a sponge cake.

When the hard lava layer cracks, it also allows water to infiltrate, seeping down into the underlying weak sedimentary rocks. This water movement further destabilises the slope by softening the clays and dispersing fine sediments. As the mudstones become exposed and saturated, the landscape becomes highly unstable, triggering landslides and erosion. This process releases fine silts and clays, which are then carried away by the drainage network—rivers and streams cut into the bedrock, undermining slopes and transporting sediment downstream into Northland's streams and harbours.

2.1.3 Ancient Rocks That Erode

Even Northland's oldest rocks—such as those in the Waipapa and Caples groups, which include greywacke and argillite—can be unstable, as seen in the Brynderwyn Hills, a well-known example (Figs. 4, 5). Although they are strong when unweathered, in Northland they are deeply weathered and often contain zones of weakness. The combination of deep weathering and zones of weakness make these ancient basement rocks prone to failure during heavy rain or when disturbed by

development. The fact that landslides and other slope failures are also common in areas still covered by native forest confirms the inherent instability of these rock types, showing that land use alone is not the only determining factor—geology plays a major role. Importantly, existing soil maps do not classify the soils formed from the weathered sediments of these ancient rocks as particularly erosion-prone, yet areas such as the Brynderwyns are well known for their instability and sediment generation.

2.1.4 Stable Areas

Of course, not all of Northland is erosion prone. Many low-lying areas, especially those with well-drained soils and areas of flat volcanic lands—such as those formed by the Kerikeri Volcanics and Waipoua Basalts—have weathered into more stable landforms. These areas are typically characterised by deeper regolith, gentler slopes, and relatively low susceptibility to mass wasting and surface erosion.

Similarly, steep landforms composed of strong, coherent rock—such as cliffs formed by the Tangihua Volcanics or Waipoua Basalts—may appear unstable, but do not necessarily contribute significant volumes of erodible material. While slips can still happen in some areas, they often involve chunky or coarse material that doesn't travel far. This kind of debris is less likely to harm waterways, because it doesn't release the fine silts and clays that cause the most damage to aquatic life.

These areas represent parts of the landscape where the impact of erosion is naturally lower—either because the landform is intrinsically stable, or because the materials being mobilised are less likely to cause downstream harm. Identifying these stable or low-risk zones is important for prioritising erosion control efforts elsewhere, where finer, more mobile sediments are generated and transported.

3 Understanding Erosion and Mass Wasting

Erosion and mass wasting are both natural processes that move soil, rock, and other materials across the landscape—but they work in different ways and can have different impacts. Both are important in understanding sediment loss and land instability in Northland.

Erosion refers to the gradual wearing away and movement of surface material by external forces such as wind and water, in the form of rain, rivers, waves, or ice. It can happen slowly, over long periods of time, or suddenly during extreme weather events. In Northland, riverbank erosion, coastal erosion, and **tunnel gullying** (erosion beneath the surface that forms underground tunnels) are particularly widespread and problematic. These processes can undercut slopes, damage infrastructure, and reduce land productivity.

Mass wasting, by contrast, is the downslope movement of material due to gravity. It includes events like landslides, earthflows, and soil **creep** (**terraces** or 'sheep tracks' on a hillside), and can happen either slowly over months or years, or suddenly (e.g., slips after heavy rain; Fig. 6).

Type of Movement	Materials	
	Rock	Soil
Landslides with variable water content and rate of movement	Rotational	
	Slump(a)	Slump(b)
	Translational	
	Rock slide(c)	Soil slide (slip)(d)
Falls	Rock fall(e)	Soil fall
Flows	Rock creep	Soil creep(f)
	Unconsolidated rock and soil (saturated)	
	Earth flow(g)	
	Debris flow / mud flow(h)	
	Debris avalanche(i)	
Lateral spread	Rock(j)	Soil
Subsidence	Rock(k)	Soil
Complex	Combination of slides, slumps, and flows(l)	

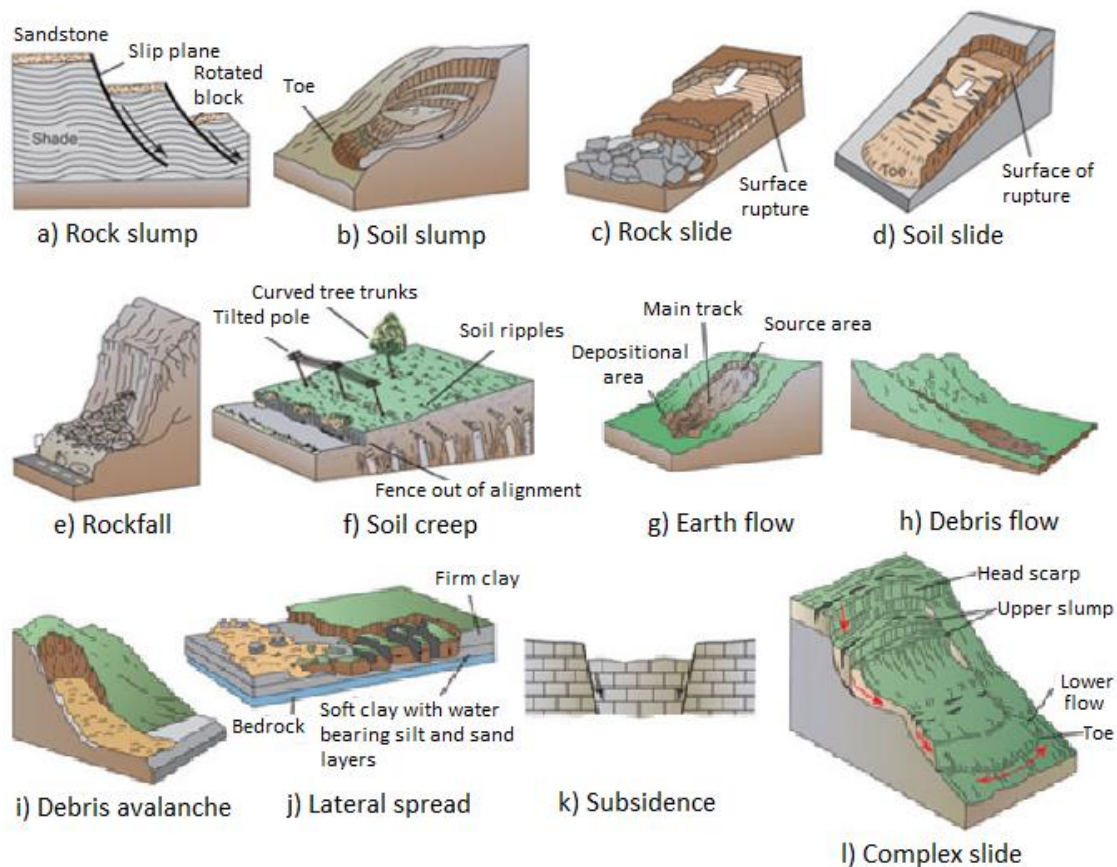


Figure 6 Landslide classification by Varnes (1978) and Cruden and Varnes (1996) based on the type of movement, material and rate.

Mass wasting induces steep changes in the age and degree of weathering of earth materials that result in distinct geochemical gradients that are detected by airborne gamma-ray spectroscopy.

Mass wasting events are typically classified by:

- The type of material involved (e.g., soil, clay, rock, organic debris)
- The type of movement (e.g., sliding, flowing, falling, creeping, or **toppling**)
- The speed of movement—from gradual shifts over decades to rapid slips or debris avalanches

3.1 Why Are These Processes Important in Northland?

Erosion and mass wasting are both major forces shaping Northland's landscapes. They influence slope stability, contribute to sediment loss, and deliver material to rivers, estuaries, and coastal environments. In hill country, mass wasting is often the dominant process—particularly during and after storms—when slips, slides, and slumps release large volumes of sediment downslope.

Research across New Zealand shows that mass wasting frequently outweighs river erosion as the primary process shaping steep hill and high-country environments (Crozier, 2010). Still, these processes often interact closely, and it's not always clear where one ends and the other begins. However, erosion processes that do not involve large slope movement—like tunnel gullying, riverbank collapse, or coastal retreat—are also common and impactful in Northland. These processes can be sporadic and tied to major weather events but still cause significant damage.

Land use changes—especially the removal of native forest for pasture or horticulture during the 1800s and 1900s—have made Northland's landscapes more vulnerable to both erosion and mass wasting. Without trees and shrubs to intercept rainfall, re-evaporate water, and anchor the soil to the deeper bedrock with their roots, the land can lose much of its natural stability and become more prone to disturbance. This greatly increases the risk of both surface erosion and slope failure by mass wasting. Once a major erosion or mass wasting event occurs, the exposed soil becomes even more susceptible to further degradation. Rainfall and runoff then carry sediment into the river network.

These processes not only reshape the land but can also reduce land productivity, damage property and infrastructure, and contribute to declining freshwater and estuarine health due to sedimentation.

3.2 Stream Bank Erosion in New Zealand Catchments: Importance, Variability, and Uncertainty

Stream bank erosion is an important—but highly variable—source of sediment that ends up in rivers, estuaries, and harbours across Aotearoa New Zealand. In some catchments, especially those with soft sedimentary rocks and large, fast-flowing rivers, eroding stream banks can contribute a large share of the sediment that discolours waterways. In some cases, studies have estimated that more than 90% of the sediment in a river may come from crumbling banks (Hughes et al., 2016; Huirama et al., 2021). But this isn't true everywhere.

The amount of sediment coming from stream bank erosion depends on many factors, like how big the stream is, what kind of rock or soil it flows through, how the surrounding land is used, whether native vegetation is still present, and how the flow changes during the year (Smith et al., 2019; Phillips et al., 2022). In the many smaller streams across the country—especially those with healthy vegetation or gentler flows—bank erosion is often very limited. In these cases, most sediment comes from erosion happening elsewhere in the catchment, such as slips or hilltop runoff.

Larger rivers, on the other hand, have more energy and wider channels, which makes bank collapse more common—especially in areas where the soils are mostly silt and clay. As rivers become stronger and faster, they're more likely to cut into their banks and cause slumping or collapse (Smith et al., 2019). This is why big rivers can contribute more sediment overall than smaller streams, even though there are fewer of them.

That said, stream banks are not always the main source of sediment. In many areas, sediment also comes from surface runoff, erosion on hillsides, or old sediments stored in floodplains and gullies that get washed out again over time (Gellis et al., 2013).

The share of sediment coming from stream banks varies a lot—ranging from just 7% in some places to over 90% in others. It depends on the type of landscape and how the estimates were made (Dietrich et al., 1999; Hughes et al., 2016). Areas with soft, easily eroded geology, steep valley sides, or cleared riparian margins are usually more prone to bank erosion (Fuller et al., 2024). In contrast, erosion tends to drop where banks are protected by fencing, riparian planting, or changes in land use—but even then, the results can vary depending on the location (Hughes et al., 2016).

3.2.1 What the Science Tells Us — and What It Doesn't

Even though stream bank erosion can be a major source of sediment, it remains one of the hardest parts of the sediment story to measure accurately. Studies in New Zealand and overseas have shown that different methods can give very different results—even when looking at the same stream.

For example, in the Chesapeake Bay area in the United States, Gellis et al. (2017) found that stream banks released a lot of sediment during storms, but that other sources—like hillsides or older stored sediment—were more important during normal flows. Similarly, research in Minnesota showed that stream banks contributed more sediment in the lower part of the river, but not upstream (Anderson and Gutzmann, 2023). These examples show that *where* a stream is in the landscape can make a big difference.

In another study, Gamble (2021) tested a commonly used tool for predicting bank erosion and found that its estimates often didn't match what was actually happening on the ground. The tool wasn't accurate unless it was carefully adjusted for local conditions.

Other studies have found that even the type of analysis used can strongly affect the results. For example, Malhotra et al. (2023) used lab testing and computer models to study an urban catchment and discovered that stream bank contributions varied a lot depending on how the data was processed. Sometimes the banks looked like the main source of sediment, and sometimes they did not.

Long-term studies, like that by Noe et al. (2022), found that stream bank erosion and floodplain sediment storage can vary widely from place to place—even within the same region. Things like land use, geology, and whether the stream is large or small all influence how much erosion occurs. Urban streams, for example, were often less stable, but still showed big differences depending on the site.

The overall message is clear: stream bank erosion is difficult to measure with confidence. The results can vary depending on when and how the measurements are taken, what part of the stream is studied, and what method is used. As other researchers have also found (Sharific et al., 2013; Vale et al., 2022), even studies done in the same place using different methods can reach different conclusions—showing just how complex this issue is.

3.2.2 Implications for Water Quality and Land Management

For people managing land and water, this uncertainty really matters. Stream bank erosion is easy to see—especially where there's been stock access, channel straightening, or flooding—but working out how much sediment it actually contributes downstream is more complicated than it looks.

This doesn't mean it's not important. In many places, reducing bank erosion can clearly improve water quality. But decisions like fencing, riparian planting, or bank stabilisation should be based on good local evidence—not assumptions or studies that do not sample intensively the many varied sources within a catchment or fail to use multiple different measurements and methods for assessing the relative contributions from different parts of a catchment. It's important to understand how all sediment sources fit together, including banks, hillsides, gullies, and older deposits that may become active again.

In short, stream bank erosion is an important part of the sediment story in many catchments—but it's not always the biggest source, and it's not easy to measure. To manage it well, we need long-term monitoring, multiple sources of evidence, and careful interpretation of what the data is really telling us.

3.3 The Role of Sediment Size and Organic Matter in Water Quality Impacts

Not all sediment is the same. When it comes to water quality, the size of the material matters. Fine sediments—like silts and clays—are more likely to stay floating in the water for longer and can cause more harm to streams, rivers, and estuaries than heavier, sandier material that settles quickly. Coarse materials such as sand, gravel, cobbles, and boulders typically settle quickly and are less likely to be transported over long distances in river systems. These larger 'particles' don't tend to transport nutrients nor pathogens (microbes or 'bugs'), nor do they typically clog aquatic habitats, making them relatively harmless in terms of downstream water quality effects.

In contrast, fine-grained materials—particularly silts and clays—pose a much greater risk. These particles can remain suspended for extended periods, are easily mobilised during runoff events, and can travel long distances through river networks. They are also highly effective at binding and transporting nutrients and bugs. As a result, they are the primary drivers of turbidity, reduced light availability, and sediment deposition in sensitive aquatic ecosystems such as estuaries, wetlands, and lowland rivers.

Along with mud and fine soil, sediment often carries organic matter—like bits of leaves, roots, manure, and pieces of topsoil or pasture. These materials are easily picked up by water running off bare ground or paddocks. They're rich in nutrients like nitrogen and phosphorus, which plants need to grow. But when too much of this nutrient-rich material ends up in streams or rivers, it can cause problems like algal blooms and poor water quality.

3.3.1 The Quality of Sediment: An Often Ignored but Critical Factor

It is important to recognise that the nutrient content of sediment is not uniform across the landscape. A kilogram of eroded topsoil from improved pasture, plantation forestry, urban drainage infrastructure, or horticultural land typically contains far more nitrogen, phosphorus, and in some instances faecal matter than the same quantity of sediment from a natural state area.

Some sediment comes from native forests and natural landscapes, but these sources have generally remained steady over long periods—sometimes hundreds or even thousands of years. They reflect natural processes and, on their own, usually don't cause major water quality issues. However, climate change may be starting to change this, with more intense rainfall events increasing erosion even in areas that were once considered stable. Still, in most cases, the larger and more immediate impacts come from human land uses, whether urban, industrial, or rural, where erosion happens faster and the sediment often carries more nutrients, bugs, and, in urban and industrial areas, heavy metals. This nutrient-rich material can quickly affect the health of rivers, streams, and estuaries.

Understanding these distinctions is critical for effective erosion and sediment management. It shifts the focus from simply measuring how much sediment is being mobilised to examining what kind of sediment is being lost—and how it behaves in receiving environments. This distinction is central to the concept of sediment quality, which considers not only the physical properties of sediment (such as particle size) but also its chemical composition, including nutrient and contaminant content. A more targeted and effective approach to sediment source tracking and mitigation should be careful to account for both the quantity and quality of sediment, recognising that some sources contribute disproportionately to environmental degradation due to their finer texture and higher nutrient loads.

4 Why Geology Is the Foundation of Erosion and Mass Wasting Risk

While many natural and human-driven factors contribute to erosion and slope instability, underlying geology is the most influential. Numerous studies have shown that the type of rock, how it has been shaped over time by pressure (such as faulting, folding, and layering), and how weathered it is all help explain where and why the land becomes unstable—especially when these factors interact with slope, water, and land use.

Key contributing factors include:

1. **Rock and soil type**

Some materials are naturally weaker or more absorbent than others. Deeply weathered, soft or porous rocks, and clay-rich soils absorb water and are also prone to **slaking** and **dispersion**, meaning they can fall apart when saturated. These are more prone to both mass wasting and erosion—especially during and after storms.

2. **Slope steepness and terrain ruggedness**

Steep and rugged land is generally more prone to erosion or slipping, especially when slopes are disturbed by things like roads, tree clearing, or flowing water. But slope on its own doesn't tell the full story. Whether land holds together or gives way also depends on what the underlying material—the regolith—is made of. Softer, clay-rich, or highly weathered material can fail even on gentle slopes when it gets wet. In contrast, firmer or better-bound material may stay stable, even on steeper hillsides. This means we need to consider both slope and the nature of the regolith—not just how steep the land looks on a map.

3. **Water pressure within the ground**

When water fills the tiny spaces within the regolith—the loose material above bedrock—it increases pressure inside the ground. This pressure, known as **pore pressure**, can act like a lubricant, making the regolith more likely to slip, especially in areas without deep-rooted vegetation to hold it together. Over time, repeated wetting and drying causes the regolith to slowly shift downhill—a process known as **soil creep**. This is common on sloping land and can even be seen in satellite observations, which show the ground slowly shifting—expanding when wet and shrinking when dry.

4. **Geological structure**

Some parts of the landscape are naturally less stable—for example, where hard rock sits on top of softer material like mudstone, or where the layers of rock have been bent, broken, or cracked over time. These areas often let water collect in the weaker layers underneath, making slips or landslides more likely when the ground becomes saturated.

These **geostructural** conditions—meaning the way rocks are layered, cracked, or folded deep within the land—are common in Northland and help explain why some areas are much more prone to erosion and land movement than others. When steep slopes, soft, clay-rich or deeply compromised regolith, and heavy rainfall come together, they create the perfect conditions for slips and sediment loss—regardless of how the land is being used.

4.1 Unpacking the Deeper Geological Controls on Erosion and Mass Wasting

The previous section outlined the key factors that influence erosion and mass wasting in Northland—highlighting geology as the most important of these. In this section, we look more closely at how geology exerts that influence, focusing on how layers of rock and regolith are arranged beneath the surface, the presence of features like faults and folds, and how weathered materials behave over time.

Erosion risk cannot be accurately assessed from surface conditions alone. What lies beneath the ground—its composition, layering, and how it holds or moves water—often determines how slopes respond to pressure. Many areas that look stable based on slope, vegetation, or soil type may in fact sit on weak or deeply weathered regolith that can fail when saturated or disturbed.

To understand why some landscapes fail repeatedly while others remain intact, we need to look beyond surface maps and consider the deeper geological makeup of the region. This includes not only the strength and type of the rock and regolith (stratigraphy), but also how past tectonic activity has bent, broken, or shifted those layers—creating weak zones where movement often begins.

4.1.1 How Rock Layering Affects Slope Stability

In many parts of Northland, hard volcanic rocks like the Waipoua and Kerikeri Basalts overlie softer, clay-rich mudstones. Water can seep through cracks in the harder rock and into the weaker material below, reducing its ability to hold together. When saturated, these lower layers may fail, triggering large-scale landslides and sediment loss. This kind of layering—called stratigraphy—can create hidden weaknesses in the landscape that aren't visible on the surface but become active during heavy rain or land disturbance.

4.1.2 The Role of Faulting and Folding

Faults (cracks in the Earth's crust) and **folds** (bends in layered rock that often cause fracturing) are common in Northland's geology. These features often bring hard and soft materials into direct contact—for example, a solid rock resting against a weak one—creating natural weak spots. They also allow water to move into deeper layers, increasing the risk of slips when those layers become saturated. As a result, landslides and slumps are often seen near these zones of disturbance, with the area of increased risk sometimes stretching several kilometres from the fault or fold.

4.1.3 How Hill and High-Country Catchments Evolve: Butler's K-Cycle Model

As discussed earlier, both erosion and mass wasting are natural processes that shape Northland's landforms. These are not random events—they are part of longer-term patterns that reflect how the land responds to geology, climate, and land use over time. One way of understanding this is through Butler's **K-cycle**, a concept developed in the mid-20th century by Australian soil scientist B.E. Butler (Butler, 1959; 1967).

Originally applied to hill country in south-eastern Australia and adapted for application to New Zealand, the K-cycle describes how steep, weathered landscapes go through repeating phases of stability, disturbance, and recovery. It includes both surface erosion (like sheetwash and gullying) and deeper movement (like slips and creep) as part of how landscapes naturally evolve.

The K-cycle has three main stages:

1. **Stability:** Soils develop, vegetation grows, and the land appears settled.
2. **Disturbance:** Slopes become unstable due to climatic events, earthquakes, or human activity (e.g., tree clearance, earthworks), and erosion or slope failure occurs.
3. **Renewal:** Over time, and with reduced disturbance, the land begins to stabilise again. New regolith forms and vegetation re-establishes.

This cycle can repeat many times. However, not all areas move through the cycle at the same pace. Some catchments with strong, well-structured regolith and good drainage may remain stable for long periods. Others—particularly those with soft, clay-rich, or fragile regolith—are more likely to shift back into disturbance when pressure builds again, such as after land use change or storms.

In this way, the behaviour of the landscape over time is strongly influenced by geology. How often slips or erosion occur, and how quickly the land can recover, depends on:

- The type of rock and regolith and how weathered it is
- The presence of faults, folds, and weak layering
- The nature and frequency of disturbance, whether from people or natural events

In Northland, many hill country areas were significantly reshaped in the late 1800s and early 1900s, when large-scale vegetation clearance and land development began. These changes pushed some catchments out of long-term stability and into a repeating disturbance cycle. Whether or not these areas return to a stable phase depends on how long they're given to recover—and whether new pressures are added in the meantime. One of the most significant emerging pressures is climate change. More frequent and intense storms, droughts, and rainfall extremes are increasing the likelihood of slope failure, erosion, and regolith disturbance—even in areas that were previously considered stable.

This is not about blame. It's about recognising the land's natural limits. Much of Northland is geologically sensitive—made up of weathered regolith, soft rocks, and complex faulting, folding, and layering. In these places, even small changes to vegetation, drainage or land surface conditions can trigger much larger changes below the surface.

Many land managers are already taking steps to reduce erosion and support recovery. But in sensitive landscapes, even well-managed areas may stay in a disturbed phase longer than expected. The K-cycle helps explain why that happens—and how, over time, recovery is still possible. It offers a practical way to understand how landscapes evolve, and how geology, land use, and natural forces all play a part in shaping what we see on the land today.

4.2 International Evidence for Geological Controls on Sediment Load

A growing body of international research shows that the type of rock beneath a catchment—not land use or even climate—is the main factor controlling how much sediment it naturally produces. One major study by Pitlick et al. (2008), based on rivers in Colorado and global data, found that geology—especially the types of rock, the shape of the land, and the size of the catchment—explained around 65% of the differences in how much sediment rivers carried. Of these, rock type and its strength were the most important. Softer, weaker rocks—like many of the mudstones found in Northland—tend to produce large volumes of fine sediment. In contrast, hard volcanic rocks like the Kerikeri and Waipoua basalts release much less.

Climate—such as rainfall and temperature—accounted for another 14%, with the rest explained by land use. This tells us that the physical makeup of the landscape—its rock strength, internal layering, and geological history—sets the natural baseline for how erosion and sediment loss occur. However, as climate change brings more frequent and intense storms, the influence of climate on erosion is likely to increase. Even areas that were once considered relatively stable may experience more frequent disturbance under shifting weather patterns.

Although Pitlick's work focused on mountainous rivers in the USA, many other studies from around the world have found the same thing: geology sets the stage. The kind of material that makes up the land—how weathered it is, how well it holds together, and how it responds when wet—all influence how easily it breaks down and moves. This is especially true for the regolith, the weathered layer of material above bedrock that includes the soil and deeper, looser deposits.

This doesn't mean land use doesn't matter. It does—but mostly in how it affects the way sediment is released, not whether the land is naturally prone to it. Even with careful management, areas underlain by soft or weathered material are more likely to produce sediment than those built on strong, well-bound rock.

Northland's geology is very different from Colorado's, but the same principle applies: the type of regolith and the strength of the material it comes from—including the presence of faults, folds, and layers—play a major role in how stable or unstable the land is. Understanding this helps, rather than undermines, good land management. When we know where the land is naturally more fragile, we can design better, more targeted responses. Geology helps us see where the risks are; management helps us decide how to respond.

4.3 Why Surface Clues Aren't Enough: Limits of Shallow Erosion Mapping

Because the type and structure of the land beneath the surface plays such a strong role in erosion, relying only on what we see at the surface—like slope steepness or soil type—can give an incomplete or even misleading picture of how likely an area is to lose sediment. Many soil erosion models focus on just the top layer of the land, mainly looking at slope and soil properties. But often, the real drivers of erosion and land movement lie deeper—within the full regolith and the geological structure underneath.

Things that often get overlooked when we only look at the surface include:

- How strong or weak the underlying rock is, and how weathered it has become
- The way different layers of rock or sediment are stacked underground
- The presence of old faults and folds—features that create hidden weaknesses
- How the land's structure affects how water moves and builds up pressure below the surface

Because of this, some places may look stable at first glance—especially when judged using standard soil erosion maps or short-term field checks—but may still be at high risk of slipping or collapsing under the right conditions, such as during heavy rainfall or land disturbance.

In Northland, many areas that are known to be erosion-prone show few clear warning signs until failure happens. Without looking deeper into the ground, we risk underestimating which parts of the landscape are truly vulnerable—especially in places where the regolith is soft, fractured, or deeply weathered.

By combining different sources of information—such as slope shape, mineral signals from radiometric scans, geological mapping, and soil data—we can build a much clearer picture of erosion risk. These tools help us understand the processes happening beneath the surface, where much of the erosion risk actually begins. As S-PAL shows, it's the combination of what the regolith is made of, how the deeper layers are arranged, and how the land is shaped that determines where erosion is most likely—not just what we see on top.

This approach allows us to move beyond surface-level assessment. Instead, we can predict and manage erosion risk by understanding the deeper forces—geology, water movement, and landform patterns—that work together to shape the landscape we live and work in today.

5 Making the Invisible Visible: Tools for Understanding Our Landscapes

Modern science is giving us new ways to understand the land beneath our feet—not just what we can see, but the hidden layers and processes shaping our environment. Two important tools in this work are radiometric surveys and LiDAR mapping.

5.1 What is Radiometric Surveying?

Radiometric surveying is a bit like scanning the land from the air. It measures tiny amounts of natural radiation that all rocks and soils give off—mostly from three elements: potassium (K), thorium (Th), and uranium (U). These natural signals are harmless, but they can tell us a great deal about the materials just below the surface. Special sensors mounted on aircraft or drones detect these signals and build up a kind of surface-level X-ray of the land.

This technology is widely used by geologists and soil scientists around the world to map variations in rock types, identify soil differences, and understand how weathered or broken down the ground has become over time. Here in Northland, we're using it to inform a much more detailed map of the region's regolith—the layer of loose, weathered material that sits above solid rock and plays a key role in erosion, slope stability, and water movement.

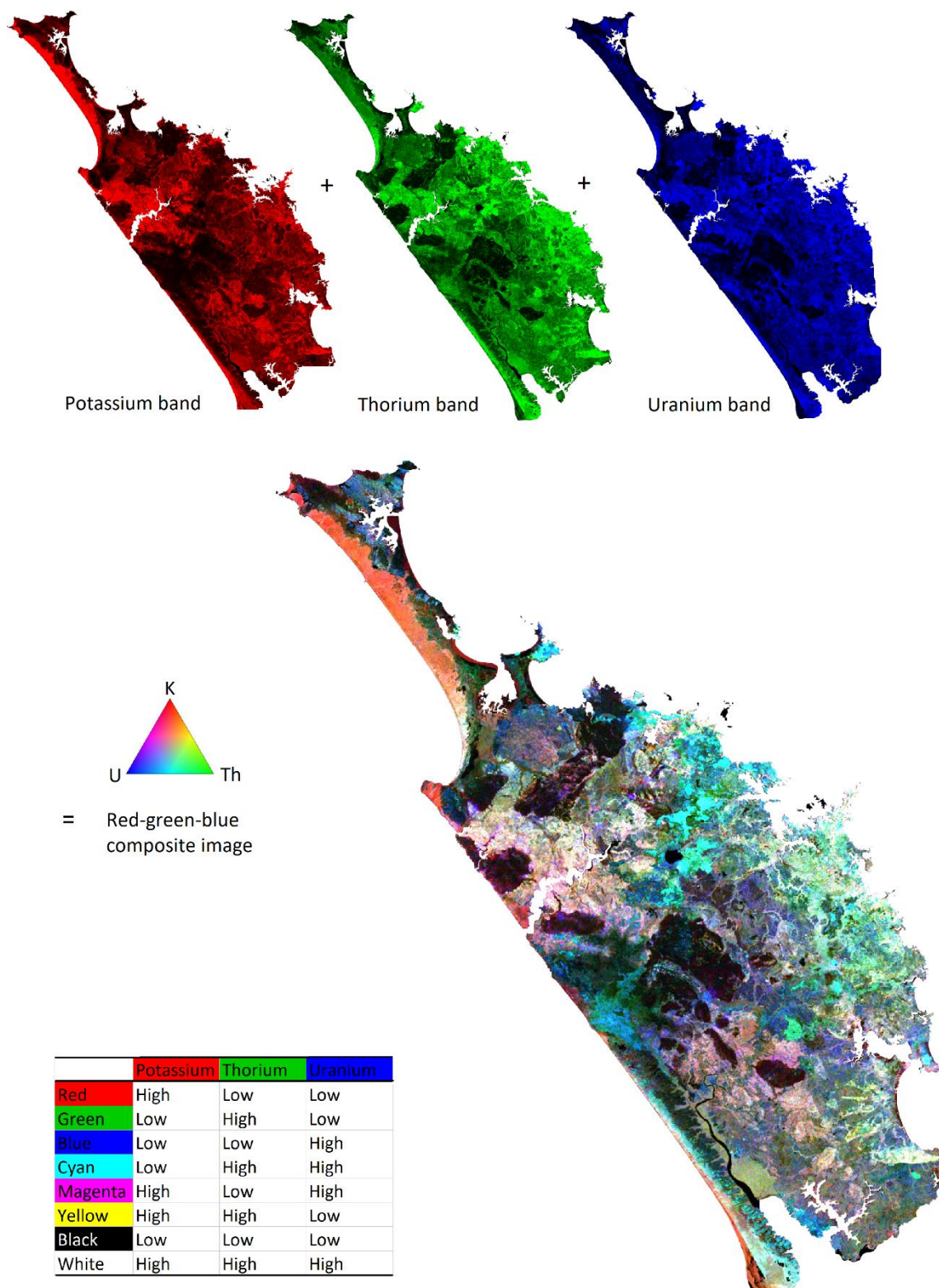


Figure 7 Airborne Gamma-Ray Spectroscopy (AGRS, 'radiometric survey') ternary image of the Northland Region (New Zealand Petroleum & Minerals, 2011).

The table of colours is produced by variable mixing of K, eTh, and eU. Northland is the only region in New Zealand with complete AGRS coverage.

Figure 7 shows a colourful map of the results of an airborne gamma-ray survey (radiometric survey) of Northland. Special sensors on aircraft measured tiny natural signals from three elements found in

all rocks and regolith: potassium (K), thorium (Th), and uranium (U). These signals were combined to create the image using red, green, and blue colours—each representing one of the elements.

- **Red** = High potassium
- **Green** = High thorium
- **Blue** = High uranium
- Other colours (like magenta, cyan, or yellow) are blends, showing areas where two or more elements are high.

What do the colours mean?

Each rock type and regolith (the loose material above bedrock) gives off a unique mix of these signals. The result is like a chemical fingerprint for the land. These colours help us understand differences in:

- **Texture:** Sandy, clayey, or loamy materials show different patterns.
- **Thickness:** Deeply weathered or thick regolith often has different signals than shallow or stony areas.
- **Degree of weathering:** Older, more weathered materials tend to lose potassium but may show enriched thorium or uranium.
- **Organic matter:** Areas with more organic content (like wetland margins or mature soils) can have different uranium signals.

In short, the different colours on the radiometric map tell us about the type and condition of the regolith—the loose, weathered material that sits above solid rock. Each colour reflects the natural mix of potassium, thorium, and uranium being emitted from the surface, and this mix varies depending on the kind of rock or sediment the regolith has formed in. For example, the combination of colours can help identify whether the underlying material is basalt, limestone, peat, or soft sedimentary rock.

But the map shows more than just rock type. It also gives clues about the texture of the regolith—whether it's coarse and sandy or fine and clay-rich—as well as its thickness and how weathered or old it is. In some areas, the colours may reflect zones where the regolith is deeply weathered and has lost its original structure; in others, it may indicate relatively young, freshly eroding material.

For instance, bright red zones often point to areas with high potassium, which may signal eroding sedimentary rock. Cyan or green areas tend to show older, more weathered zones or clay-rich regolith that holds more thorium and uranium. Very dark patches—where signals are low—can indicate hard volcanic rocks like basalt, thick peat, or even waterlogged areas where signal strength is naturally reduced.

Because Northland is the only region in New Zealand with complete airborne radiometric survey coverage, this map provides a uniquely detailed, region-wide view of what lies beneath the surface. It helps us detect variations in the regolith even where the land looks uniform from above. This makes it an especially powerful tool for improving our understanding of erosion risk, land behaviour, and long-term stability across Northland.

5.2 What is LiDAR?

LiDAR is a powerful technology that uses laser pulses from aircraft to create incredibly detailed 3D maps of the land surface. Unlike ordinary aerial photos, LiDAR can 'see through' vegetation to

capture the shape of the ground beneath. This makes it especially useful for understanding how the land is shaped—whether it's steep or flat, rough or smooth, stable or shifting.

It provides a highly detailed baseline of the land’s form, allowing us to map not just elevation, but also slope, aspect (which way a slope faces), and surface roughness. From this foundation, we can produce extremely detailed terrain models that support a wide range of applications—from erosion and land stability mapping to flood modelling and land use planning.

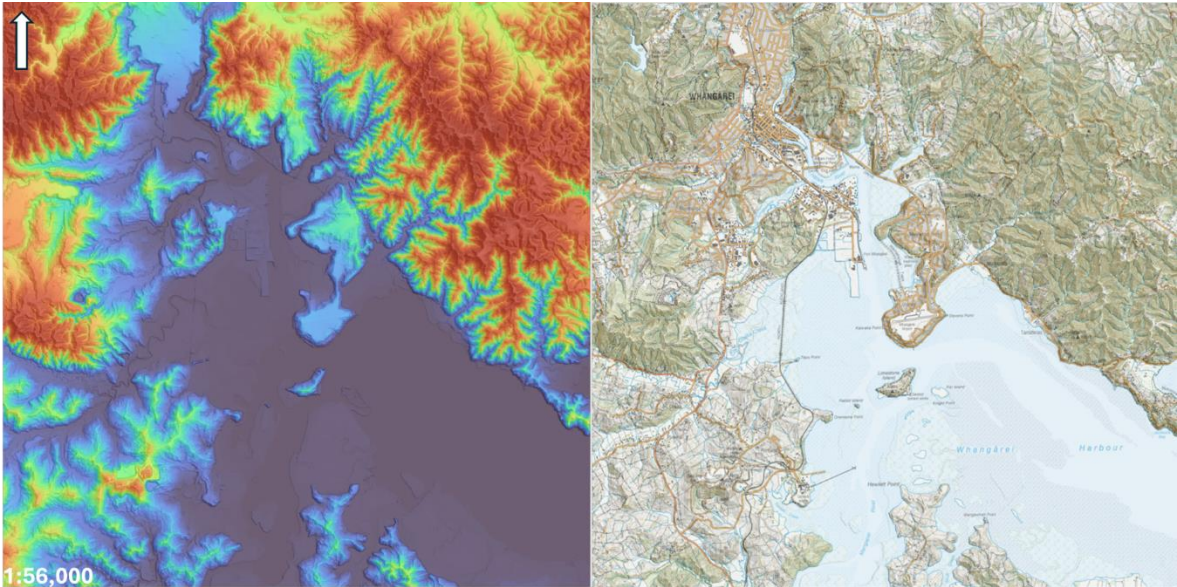


Figure 8 LiDAR-derived elevation model of Whangarei Harbour and surrounds.

LiDAR has a resolution of 1 x 1 m, and a vertical accuracy that is typically less than 0.2 m.

LiDAR is particularly useful for detecting subtle features that may not be visible to the naked eye, such as landslides, tunnel gullies, rill erosion, **sheet wash**, soil creep, and shallow slips. It also helps identify patterns in ridges, valleys, and drainage channels—giving us insights into how water moves across the landscape and where erosion might begin.

In short, LiDAR provides a high-resolution, landscape-wide view of the physical shape of the land—an essential foundation for understanding where and why erosion happens, and how different landforms interact with geology, soils, and water over time.

Table 1 Comparison of radiometric and LiDAR technologies

Feature	Radiometric Surveys (GRS)	LiDAR
Primary output	Surface chemistry—what the land is made of (e.g., soil and rock composition)	Surface shape—how the land is formed (e.g., slope, contours, terrain features)
Key strengths	Reveals weathering, soil age, mineral content, texture, and organic matter	Detects subtle terrain changes, landslide scars, and slope steepness—even under vegetation
Limitations	Only senses the top few cm to m depending on soil type and moisture; resolution is coarser (~50 m) than LiDAR, but much finer than standard soil or geology maps	Doesn't tell us anything about the chemistry or composition of soils and rocks

Feature	Radiometric Surveys (GRS)	LiDAR
Best used for	Identifying soil and rock types, assessing weathering, and highlighting zones of surface instability	Mapping erosion-prone slopes, landslides, gullies, and fine-scale terrain features

5.2.1 Seeing the Land at Every Scale: What Radiometrics and LiDAR Reveal Together

One of the greatest strengths of using LiDAR and radiometric survey together is that they let us read the landscape at multiple scales—from broad regional patterns right down to fine-grained details at the paddock level. This matters because erosion and instability don't just happen in one way or at one size. Some processes are shaped by big-picture geological forces like faulting and land uplift, while others are driven by local features—such as a sudden change in slope, a slip face, or a poorly drained gully.

LiDAR captures the detailed shape of the land—its slopes, ridges, and hollows—while radiometric survey picks up subtle chemical signals that reflect the type, condition, and age of the regolith just below the surface. Soil and geology maps provide important context about how the land was formed and what it's made of. When we combine all of these layers, we get a much clearer picture of how different parts of the landscape are connected—across scales and landforms.

Many scientists who use radiometric survey technology say that its greatest strength is this ability to visualise the land at multiple scales. It's not just about seeing patterns—it's about understanding how processes at the hill or farm scale connect to what's happening across a whole catchment.

This integrated view helps us pinpoint softer, more erodible areas, identify hazard zones such as slips or areas of accelerated erosion, and understand how surface features link to deeper geological structures like faults, folds, and buried layers of rock. For planners, landowners, and community members, this means better insight for land-use decisions, more targeted erosion control, and a deeper understanding of how the land behaves—from ridge to gully, and farm to floodplain.

While traditional soil and geological maps are still essential, modern datasets like LiDAR and airborne radiometrics allow us to see the land in much finer detail and with greater nuance. By bringing these tools together, we can better understand where erosion is most likely to happen—and why.

6 Examples of the Use of Terrain and Radiometric Survey

Radiometric surveys and LiDAR have been widely used—both internationally and in New Zealand—to better understand erosion risk and mass wasting (slope instability).

Globally, they are used to:

- Create high-resolution maps of areas prone to erosion and mass wasting
- Detect sediment source zones before problems arise
- Identify slope instability, even in areas with dense vegetation or difficult terrain

Many of these applications involve combining radiometric and terrain data to reveal patterns of surface weathering and geological weakness. This integrated approach is central to how erosion susceptibility is now being modelled in New Zealand—including in the development of S-PAL.

6.1 International Evidence from Combined Radiometric and Terrain Analysis: Proven Approaches Informing Northland's S-PAL

Research in Australia has demonstrated that airborne gamma-ray spectrometry—a technique measuring natural radiation from the Earth's surface—can help track how landscapes change over long periods by assessing the degree of weathering in surface materials.

In 2012, researcher John Wilford developed a tool called the **Weathering Intensity Index (WII)**. The WII combines radiometric measurements from potassium, thorium, and uranium with terrain features such as slope to map the extent of surface weathering (Wilford, 2012). High radiometric signals typically indicate areas undergoing active erosion or recently exposed rock, while lower signals correspond to stable areas with deeper weathering or sediment accumulation. Wilford's findings closely aligned with field observations, confirming the reliability of radiometric approaches for assessing landscape stability.

Further studies by Pickup and Marks (2000; 2001) in southeastern Australia expanded on this approach. They demonstrated that gamma-ray spectrometry, particularly potassium signals, could effectively highlight differences between erosional landscapes (areas actively losing material) and **depositional landscapes** (areas gaining material). Their work clearly showed how radiometric data could identify whether sediment movement was constrained by limited sediment supply or by environmental factors like slope and water flow, and it captured how sediment distributions changed following significant flooding events. Additionally, research by Wilford and Minty (2006) confirmed the utility of airborne gamma-ray imagery for mapping regolith and soil properties at a detailed scale across diverse landscapes, reinforcing its value for landscape assessment and management.

These Australian approaches strongly parallel the methods being applied in Northland, New Zealand, through the Sediment–Process Attribute Layer (S-PAL). In Northland, potassium anomalies are identified using a statistical method known as **MADZ (Median Absolute Deviation Z-score)**. This method compares potassium levels in smaller areas to broader regional patterns, allowing clear identification of active **erosion zones**, characterised by elevated potassium signals. Lower MADZ values, on the other hand, represent stable, mature surfaces or zones where sediment accumulates—such as gentle slopes or floodplains covered by older soils. By clearly distinguishing these different landscape activities, S-PAL provides actionable insights into erosion susceptibility and sediment dynamics, directly supporting targeted land management and conservation strategies.

6.2 New Zealand Applications from Combined Radiometric and Terrain Analysis: Proven Approaches Informing Northland's S-PAL

Building on the foundations laid by international studies, a number of regional projects in New Zealand have applied similar techniques to map erosion risk at both regional and catchment scales. These case studies show how radiometric and terrain data can be adapted to suit different landscape settings—demonstrating the flexibility and value of this approach for land and water management.

Case study Southland

A detailed regional study in Southland combined gamma-ray spectrometry with terrain ruggedness mapping to improve understanding of areas susceptible to surface erosion and slope instability (Rissmann et al., 2020). Applied scientists analysed radiometric signatures, terrain metrics like slope steepness and ruggedness, and geological features such as fault lines and rock boundaries across hill country prone to erosion. These results were then cross-checked against known erosion features, including mapped landslides and satellite imagery, to evaluate how accurately the model represented actual landscape conditions.

Key findings of this study were:

- While traditional classifications, such as **Land Use Capability (LUC)**, provide valuable historical context, additional insights from radiometric and terrain data improved predictions of erosion susceptibility.
- Integrating slope, ruggedness, and geological composition, including faults, yielded enhanced accuracy in identifying unstable areas.
- Radiometric data was particularly effective at highlighting surface materials prone to instability, such as weathered, silty or clay-rich regolith, even in regions previously identified as relatively stable.
- Specific radiometric patterns—like mottled or irregular signals—revealed areas where surface materials varied greatly, indicating uneven or disturbed regolith. Areas with highly irregular or strong signals were often linked to larger landslides or significant instability, highlighting places where the regolith had recently moved or been disrupted. This approach aligns closely with methods like the K MADZ anomaly detection used in Northland, which also identifies active areas based on similar variations in radiometric potassium signals.

This study illustrated that integrating modern radiometric and terrain analyses with traditional classifications can provide a more nuanced and predictive understanding of regional erosion susceptibility, supporting improved land management and conservation strategies.

Case Study: Te Hoiere Pelorus Catchment, Marlborough

In Marlborough's Te Hoiere Pelorus Catchment, applied scientists explored sediment generation and transport at the catchment scale (Pearson et al., 2024). The study utilised gamma-ray spectrometry to map differences in the stability and weathering of surface materials, alongside LiDAR data that detailed slope and terrain characteristics.

Unlike the broader regional study in Southland, this Marlborough analysis was targeted at identifying specific sediment pathways and accumulation areas within a single catchment. Key outcomes included:

- Steep, highly weathered, or exposed slopes were identified as primary sources of sediment.
- Gamma-ray spectrometry effectively distinguished areas impacted by past erosion events or recent disturbances, such as forestry activities.
- Combined terrain and radiometric analyses pinpointed specific sub-catchments disproportionately contributing to sediment loads, enabling targeted management and restoration efforts.

Together, these New Zealand case studies—Marlborough and Southland—demonstrate the versatility and effectiveness of integrating gamma-ray spectrometry and LiDAR-based terrain analysis. These approaches can significantly enhance traditional mapping methods, supporting both detailed local interventions and broader regional planning initiatives for land resilience and sustainability.

Building on these approaches, Northland was the first region in New Zealand to systematically combine radiometric survey and terrain measurements to comprehensively classify regolith and assess erosion susceptibility at a regional scale. This innovative framework led to the creation and ongoing development of the Sediment–Process Attribute Layer (S-PAL).

7 Northland's Sediment Process Attribute Layer (S-PAL)

Together, the Marlborough and Southland case studies highlight the flexibility and utility of combining gamma-ray spectrometry with detailed terrain analysis across diverse landscapes and scales. However, Northland was the first region in New Zealand to systematically integrate these radiometric and terrain datasets to classify regolith and map erosion susceptibility comprehensively at a regional scale. The resulting approach—known as the Sediment–Process Attribute Layer (S-PAL)—has since informed similar work across other regions.

As with the Australian examples, the Sediment–Process Attribute Layer (S-PAL) is a detailed mapping tool created to help people understand which areas of Northland are naturally more or less likely to experience erosion or landslides. It identifies places that might have issues like soil slipping downhill or sediment washing into waterways. Originally developed in 2018, S-PAL has since been significantly improved using better data, new scientific insights, and modern analytical techniques.

To manage erosion effectively in Northland, it's important to recognise that soil loss usually involves both surface and deeper subsurface processes. While surface runoff during heavy rainfall can wash soil downhill, deeper conditions within the land also strongly influence erosion and slope failure. Focusing only on the upper soil zone can overlook the more critical, and often less visible, forces that cause land to fail.

At the heart of this is the regolith—a blanket of loose, unconsolidated material that lies above solid bedrock. The regolith includes the soil but extends much deeper, encompassing layers of weathered rock, ancient slope, river, swamp, or marine deposits. This layer has formed over thousands or millions of years and plays a vital role in determining how the land holds together, absorbs water, and responds to pressure or disturbance. When saturated or weakened, the regolith can fail at the surface or deeper down, triggering slips, slumps, or landslides.

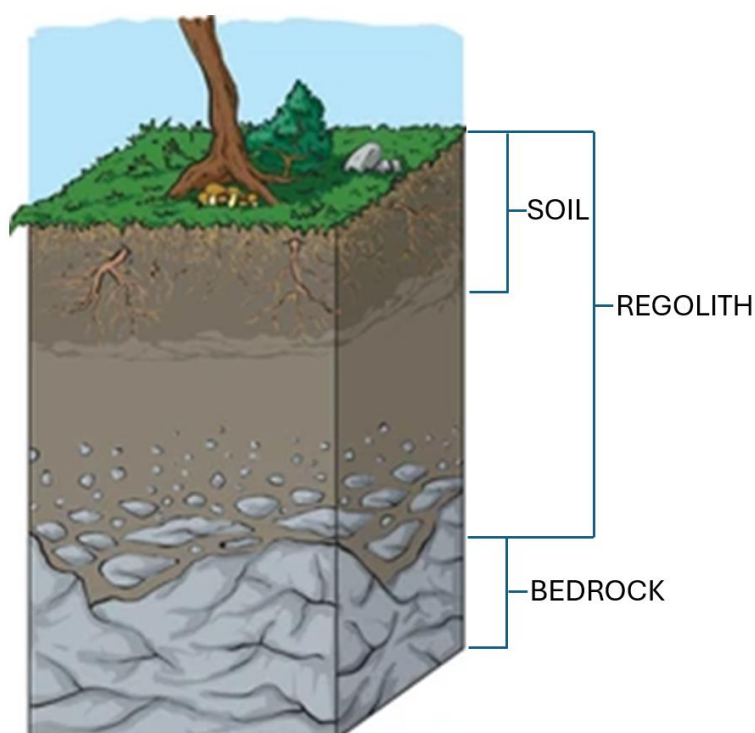


Figure 9 A diagram of the regolith.

The regolith includes the soil and weathered materials overlying unweathered bedrock. The depth of the regolith varies from place to place, including the thickness of the soil component.

Because the regolith plays such a central role in erosion, understanding its character is essential. Northland's regolith is highly variable, reflecting the region's diverse geological makeup. Some areas rest on hard volcanic rocks or marine limestones, while others lie on softer, more erodible materials like sandstone, mudstone, or unconsolidated river and coastal deposits. These variations shape the depth, texture, and weathering of the regolith—key traits that affect its stability.

7.1 The S-PAL, A Regolith Classification

The S-PAL was designed to map the natural variation in the regolith objectively, using actual measurements rather than assumptions. The aim was to identify and classify the different types of regolith found across Northland. As the type of landform, the nature of the underlying rock or sediment, and the regolith's depth, texture, and degree of weathering vary, so too does its potential to erode. The S-PAL captures this variation using two core datasets:

- **LiDAR Data:** High-resolution (1 m) 3D scans of the land surface that show terrain shape, steepness, and surface roughness in detail.
- **Radiometric Data:** Airborne surveys collected at a 50-metre resolution that detect natural radiation emitted by minerals in the ground. These signals reveal differences in material type and degree of weathering, offering a kind of chemical fingerprint of the regolith.

These datasets are analysed using statistical and mathematical methods, allowing the natural groupings in the data to emerge—essentially letting the data speak for itself. This approach creates a data-driven classification of Northland's regolith, not based on existing maps or expert opinion, but on measured physical and chemical traits. In this way, think of S-PAL like a regional family tree for the land—it groups different parts of Northland based on how similar their regolith is. Just like a family tree links people by shared traits, S-PAL links areas of land that share similar features, such as land shape, rock type, or how weathered and thick the surface material is.

This hierarchy has three levels:

- **Domain Level (Broadest Level):** Groups land by its general shape—steep and rugged, gently rolling, or flat and low-lying.
- **Family Level (Middle Level):** Groups areas based on the type of underlying rock or sediment, such as basalt, sandstone, or river-borne gravel.
- **Sibling Level (Most Detailed Level):** Identifies fine-scale variation in regolith traits, including thickness, texture, and age (degree of weathering).

Importantly, the S-PAL **regolith classification** is not a prediction of erosion—it's the foundation from which susceptibility can be assessed.

Refer back to Figure 2 to view the S-PAL classification, which illustrates the 12 main regolith families across the Northland region. While this figure provides a broad overview, the sibling level offers much finer resolution and variability, which is difficult to convey in a simple text document.

7.2 A Strong Match with Geology—Without Using It Directly

Even though S-PAL does not include geological maps in its classification process, the result aligns remarkably well with known geology. In fact, when the S-PAL siblings were compared to **Q-MAP**, New Zealand's national geological survey, they showed a strong and intuitive match. Where Q-MAP identifies general rock types, S-PAL classifies fine scale variability in the properties of the regolith.

To test this alignment, a machine learning model (called a random forest) was used to see whether S-PAL could correctly predict the Q-MAP geology of Northland. The model was validated using a method called **out-of-bag (OOB) testing**, and it achieved 80% accuracy—an impressive result given

that geology was never used as an input. This tells us that the regolith is so closely tied to its geological structure that S-PAL can ‘see’ geology indirectly through the regolith classification.

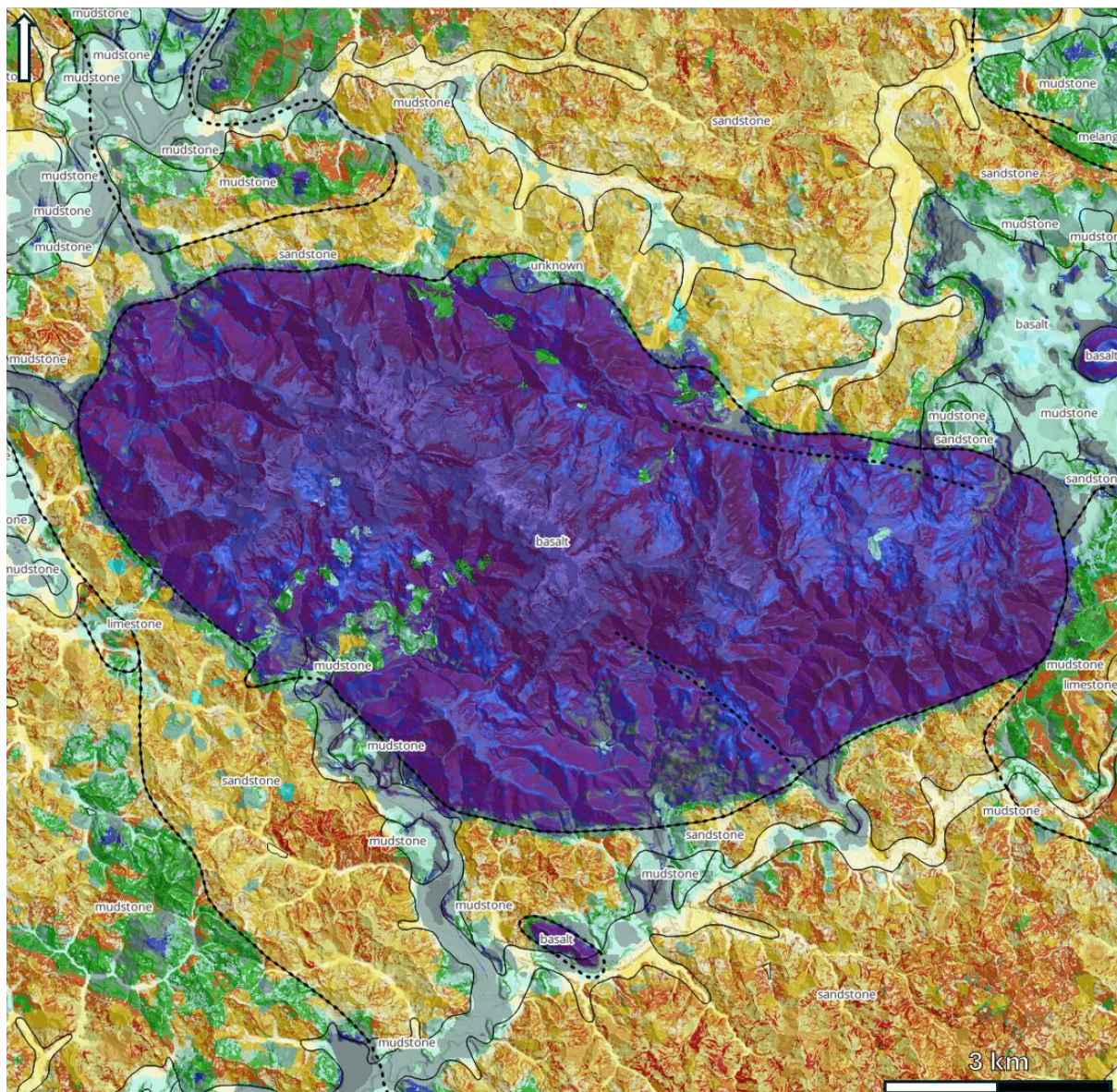


Figure 10 Q-MAP geological units (black outlines) and names overlaid on the S-PAL Regolith Classification.

Importantly, the comparison also reveals that S-PAL Regolith Classification captures much finer detail than is currently shown by Q-MAP or soil maps on their own. Even at a local scale—such as in Figure 11, which covers a 20 km wide area—the match with geology is excellent, but S-PAL picks up subtle spatial variation in regolith character that geology and soil maps alone do not resolve. These fine-scale differences reflect differences in regolith thickness, texture, drainage, organic carbon content, and age (weathering), which are critical for understanding erosion processes at property and paddock scales.

7.3 Predicting Regolith Susceptibility to Erosion

The S-PAL regolith classification provides the starting point for understanding landscape sensitivity in Northland. By identifying the natural patterns of regolith material—how it varies in composition, weathering, and terrain—the classification gives essential context for predicting where erosion is most likely to occur. This helps explain not just what the land is made of, but how likely it is to move. This context becomes especially powerful when combined with other structural features of the landscape, such as ancient faults, folds, and rock layering visible in Q-MAP geological data. These

geological boundaries often coincide with zones of regolith instability, and the S-PAL framework helps reveal how these deeper controls influence surface behaviour.

Building on this foundation, every part of Northland was ranked using two complementary indicators: (1) how recently the land's regolith has been disturbed, and (2) how easily water flows over the land's surface. These two processes describe different types of erosion risk and are best understood together.

The first indicator—**Regolith Activity**—captures how disturbed or stripped the landscape appears to be. This is measured using potassium levels detected by airborne gamma-ray spectrometry. Potassium is a natural component of many rocks and soils, but it tends to be leached out as surfaces weather over time. High potassium signals suggest that the regolith has been recently active, i.e., exposed or disturbed, while low levels point to older, less active (more stable) regolith.

The second indicator—**Overland Flow Susceptibility (OLF)**—represents how likely rainfall is to run across the land instead of soaking in. This process is influenced by soil hydrology, slope steepness, and climate. Areas with steep slopes, compact soils, or saturated conditions tend to shed water more quickly, increasing the chance of soil erosion during heavy rain. Unlike the regolith activity layer, this indicator focuses on surface hydrological processes like rilling, sheet wash, and shallow overland flow.

These two indicators often tell different stories. For example, an area might have a high overland flow score because it sheds water quickly, but low regolith activity if the regolith hasn't been recently disturbed. Conversely, an area may have a high regolith activity score and yet a low overland flow, e.g., Brynderwyns, due to failure at the contact between the regolith and deeper bedrock. A good metaphor is a house with a cracked foundation versus one with a leaky roof. Both represent vulnerabilities, but they stem from different causes and require different responses. Recognising the difference helps in planning the right type of mitigation.

To provide a clear, usable classification of erosion risk, these two indicators were combined into a single **composite susceptibility surface**, ranked into five categories:

- Class 1 = Low susceptibility
- Class 2 = Moderately low susceptibility
- Class 3 = Moderate susceptibility
- Class 4 = High susceptibility
- Class 5 = Very high susceptibility

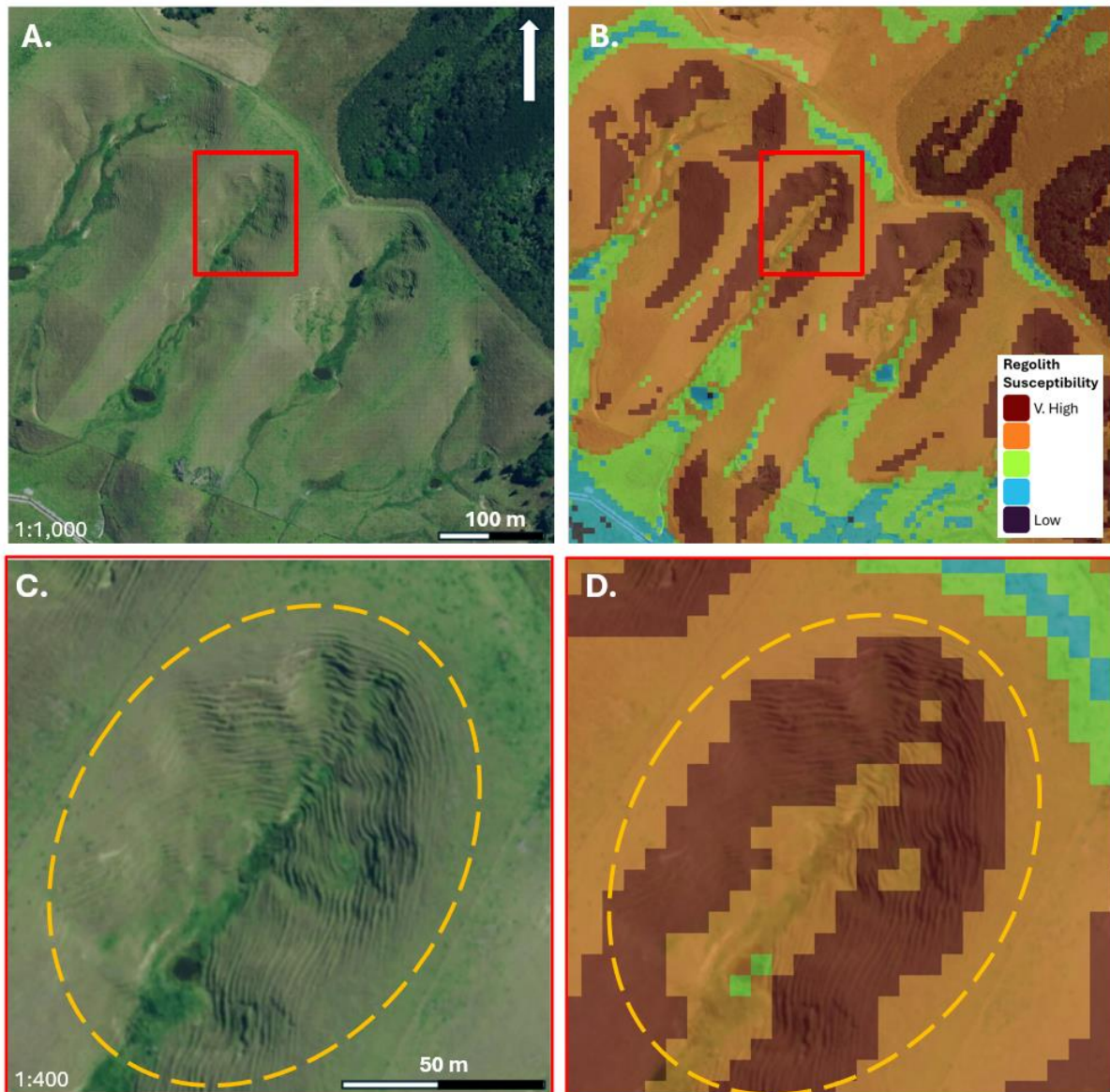


Figure 11 The S-PAL Regolith Susceptibility Classification.

A. Aerial photography of narrow incised gullies. B. S-PAL Regolith Susceptibility Classification. C. Close-up of an area of gully head and wall erosion (red rectangle insert). D. Close-up of S-PAL Regolith Susceptibility Classification (red rectangle insert). The S-PAL Susceptibility Classification works at multiple scales, from regional to property, and property to paddock scale.

Each point on the landscape was assessed based on how strong and aligned the regolith activity and overland flow signals were. Highest susceptibility (Class 5) indicates places where both indicators are elevated. Lowest susceptibility (Class 1) means both indicators are low. Mixed classes—where one indicator is high and the other low—still signal important types of risk, just through different mechanisms.

To make these findings useful for real-world planning and land management, the erosion susceptibility scores were reconnected to each of the 7,305,438 individual regolith units identified in the high-resolution S-PAL classification. This was done using a simple method called zonal majority, where we looked at all the small cells (or pixels) inside each regolith unit and assigned it the most common erosion rating found within it.

This step is important because it links erosion susceptibility back to the type of land it's happening on. Rather than showing erosion risk as a stand-alone map, it becomes part of a richer story about how the land is built and behaves—its materials, shape, and how it has changed over time.

This makes a big difference when deciding what to do next. By placing susceptibility inside the context of regolith type, planners and landowners can better understand not just *where* the land is vulnerable, but *why*—and whether it's something that can realistically be managed or changed. For example, shallow runoff might be addressed with planting or fencing, but deep regolith instability may require different strategies—or may not be easily fixed at all. This approach helps target actions that are suited to both the physical nature of the land and the kinds of processes at play.

In practical terms, this means that users—whether councils, iwi/hapū, landowners, or planners—can immediately see not only *where* erosion might occur, but *why*. A high susceptibility value now carries meaning tied to a specific regolith class: for example, a densely faulted sedimentary **mudstone** with clear evidence of slips, slumps, and deep-seated control over sediment loss, or a fine-textured clay mantled volcano prone to runoff. Conversely, a low susceptibility rating embedded in a thick, mature regolith class indicates both surface and subsurface stability.

This contextual clarity is essential for targeting interventions effectively. It allows for planning and policy decisions that are not just spatially precise, but scientifically grounded—helping to direct erosion control to the right places, using methods tailored to the nature of the land itself.

This combined approach—built from the ground up using the regolith classification, and layered with both geochemical and hydrological evidence—provides a region-wide baseline of where Northland's land is naturally more sensitive. It helps councils, landowners, and communities better understand where to focus erosion control, plan infrastructure, and anticipate future risks, especially in a changing climate.

It is important to emphasise that this classification is based solely on physical and geochemical characteristics of the land surface. No land use information—such as farming practices, tree planting, or engineering works—was used in determining susceptibility. As such, the susceptibility layer reflects the inherent or natural tendency of the land to erode or remain stable. It does not measure the actual amount of sediment being lost, nor does it account for current mitigations or land management efforts (e.g., afforestation, direct drilling, or sediment trapping). These human influences may substantially reduce erosion, but they fall outside the scope of this intrinsic susceptibility analysis.

In short, this component of the S-PAL framework provides a region-wide baseline of where the landscape is naturally more sensitive to sediment detachment and redistribution—information that is particularly relevant for erosion management, infrastructure planning, and targeted mitigation.

7.4 Independent of Land Use and Mitigation Measures

One of the defining features of the S-PAL framework is that it is entirely based on the natural properties of the landscape. The classification does not include or consider land use, such as whether the land is in forest, pasture, horticulture, or urban development. Nor does it account for erosion control measures already in place—like planting, fencing, or detention systems.

Instead, S-PAL shows the susceptibility of land to erosion and mass movement based solely on its physical and geochemical characteristics—such as rock types, degree of weathering, faults, folds, and layering (stratigraphy), and soil runoff potential. These characteristics reflect the land's geological inheritance and long-term evolution. This makes S-PAL a useful reference layer for understanding how the land behaves under pressure—without the influence of short-term or management-related variables.

This enduring perspective is crucial. The patterns expressed in S-PAL represent an underlying sensitivity that has persisted over geological timescales—often millions of years. This sensitivity is

driven by natural landscape features such as regolith character and hydrological behaviour. While land use can influence whether this underlying susceptibility translates into actual erosion, it does not alter the susceptibility itself. Some practices can exacerbate sediment loss by disturbing or exposing vulnerable surfaces, while others may help avoid triggering erosive processes but do not remove the underlying risk.

In this way, S-PAL reflects potential, not outcome. Even where effective mitigation is in place—through practices like fencing, planting, or detention systems—sediment loss may appear low, but this reflects good management rather than a fundamental change in the land’s character. Importantly, in some landscapes, sediment loss remains difficult to minimise regardless of land use practices, because the controlling factors lie deeper—within the geological structure, weathered profile, or persistent hydrological pathways—beyond the reach of surface-level intervention. S-PAL makes these inherent limitations visible, offering a consistent baseline against which both risk and management effectiveness can be interpreted.

It is important to stress that the susceptibility ranking does not indicate how much sediment is actually being lost from a site, nor does it reflect mitigation efforts. It simply identifies areas that are more likely to lose sediment. In that sense, S-PAL provides a consistent baseline of inherent susceptibility across the region—grounded in regolith structure, not in assumptions about land management.

7.5 Scalable, Visual, Actionable

The Sediment–Process Attribute Layer (S-PAL) gives a consistent, fine-scale picture of how naturally prone different parts of the landscape are to erosion. It is based entirely on the natural features of the land—such as its shape, the depth and makeup of the material sitting above bedrock, and the way it has weathered over time. S-PAL uses high-quality data from LiDAR (which maps the land’s surface in 3D) and airborne sensors that detect natural radiation from the ground. These tools work together to show the physical structure of the land in fine detail—at scales small enough to see changes within individual paddocks, yet consistent across all of Northland.

One of the key strengths of S-PAL is that it doesn’t include land use or management. It doesn’t matter whether the land is in pasture, forest, horticulture, or urban development. It also doesn’t factor in any mitigation efforts like planting, fencing, or sediment traps. Instead, S-PAL focuses on what can be measured directly from the land itself—its shape, how deep and weathered the surface layers are, and what materials those layers are made of. This gives a stable, unbiased baseline that shows where the land is naturally more or less likely to erode, regardless of how it is being used.

Northland is in a unique position to apply this approach. It is currently the only region in Aotearoa New Zealand with complete coverage of both LiDAR and radiometric data. This makes Northland the first area where S-PAL could be applied across the entire region with high confidence and detail.

S-PAL doesn’t replace existing tools like the Land Use Capability (LUC) classification or the **Fundamental Soil Layer (FSL)**. Instead, it adds a new layer of information that helps explain why some areas are more erosion-prone than others—even when they are used in similar ways. By looking beneath the soil zone and understanding the natural makeup of the land, S-PAL helps identify which areas are more sensitive, and why.

Because S-PAL is based on measurable properties of the land, rather than expert interpretation, it can be revised over time as new data become available. Improvements in LiDAR coverage, radiometric resolution, or underlying terrain models can be incorporated into the existing framework without altering its core structure. This supports consistency over time while still allowing for technical refinement.

The working resolution of S-PAL—around a quarter hectare—is detailed enough to inform both regional-scale planning and property-scale decisions. For landowners, iwi/hapū, councils, and

planners, this allows erosion susceptibility to be examined in a way that connects broad landscape patterns with localised on-the-ground conditions. It helps identify areas where erosion risk is naturally higher due to the way the land is built—its shape, the depth and structure of the regolith, and how it responds to water.

In some places, these risks can be effectively managed with surface-level interventions, like pole planting, strategic grazing, or a shift to direct drilling. But in other areas, the factors driving sediment loss run much deeper—linked to underlying geology, deep-seated instability, or persistent subsurface water movement. These processes are often beyond the reach of typical land management. In such settings, there may be little that can be done to fully prevent sediment loss, and recognising these limitations is essential for setting realistic expectations and directing effort where it can have the greatest effect.

By grounding susceptibility in the physical nature of the land—not its current use or visible condition—S-PAL helps clarify where natural constraints are likely to limit management outcomes, and where more responsive or targeted strategies may be possible.

8 Does the S-PAL Do a Good Job of Predicting Soil and Geology?

This section outlines how we evaluated the usefulness of the S-PAL Regolith Classification in explaining mapped patterns of soil (Fundamental Soil Layer) and geology (Q-MAP). The goal was to understand which datasets best reflect broad-scale classifications already in use and how they might enhance land and water management decisions in the future. The focus was not on generating new maps or erosion estimates, but rather on assessing how well each dataset aligns with the established regional soil and geological classifications.

To do this, we selected 7,500 randomly distributed points across Northland to ensure the assessment captured the region’s full range of landforms, geology, and soils. At each location, we extracted a consistent set of environmental attributes. These included elevation, slope, and aspect (from high-resolution LiDAR); rainfall and soil moisture balance (from national climate databases); radiometric survey data capturing near-surface rock chemistry (using airborne gamma spectrometry); land use intensity (from mapped land use categories); and the S-PAL Regolith Classification sibling level assigned to each point. These datasets were chosen because they represent a combination of physical terrain, climate, surface geology, and land modification.



Figure 12 The 7,500 randomly selected sample points across the Northland Region used to evaluate S-PAL alignment with soil and geology classifications.

As some variables—such as rainfall and elevation—are closely related, statistical adjustments were made to reduce overlap and better isolate each dataset’s individual contribution. For example, rainfall tends to increase with elevation, so we adjusted the rainfall data to remove the part of its variation already explained by terrain. The same approach was used for land use and slope. This helped ensure that when we tested each dataset’s influence, we were not simply re-measuring another variable’s effect.

We compared the environmental data to two established mapping layers that describe different aspects of the land: the New Zealand Soil Classification and Soil Series (mapped at 1:63,000 scale) and geological units from Q-MAP (1:250,000). These maps served as reference layers. While they remain widely used and important for regional-scale planning, they are not designed to show fine-scale variation at the property or paddock level.

To determine which environmental variables best explained the mapped patterns, we applied a repeated testing approach that ranked each dataset by how strongly it contributed to identifying soil and geological classes. We also applied two different reliability checks, cross-validation and out-of-bag testing, to ensure the findings were robust and not influenced by random variation in the data. These checks confirmed that the results were consistent and reliable.

Among all datasets tested, the S-PAL Regolith Classification emerged as the strongest individual predictor. In relative terms, overall, its importance score was 2.2—more than double that of the next-best dataset. Radiometric data, which captures information about subsurface rock composition and surface weathering, was the second most useful dataset, with an importance score of 1.0.

Climate variables, adjusted for elevation and aspect, including mean annual rainfall and soil moisture deficit, along with elevation, each had moderate scores of 0.8, indicating they added meaningful but secondary contributions. Slope had a lower score of 0.5, followed by land use intensity at 0.3. Aspect—the direction a slope faces—had an extremely low score of less than 0.05, indicating it offered very limited explanatory value in this context.

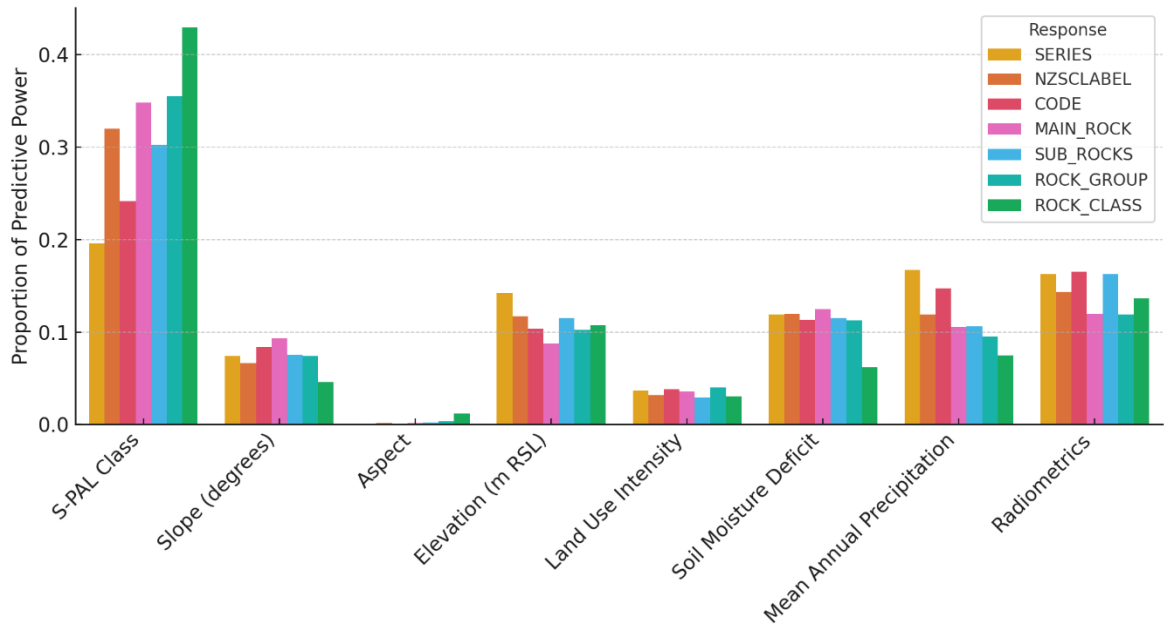


Figure 13 The relative importance or influence of the different layers and S-PAL Regolith Classification on soil (Series and NZSCLABEL) and geology (CODE, MAIN_ROCK, SUB_ROCKS, ROCK_GROUP, ROCK_CLASS).

The performance of S-PAL reflects how it was developed. It integrates fine-scale terrain data with radiometric signals to classify the landscape based on measurable physical and chemical traits—such as terrain shape, regolith composition, depth and texture, and degree of weathering.

Table 2 The relative importance of the S-PAL and other environmental variables in predicting Northland’s soil and geology.

Dataset	Relative Importance
S-PAL Class	2.2 (highest)
Radiometric Data	1.0
Mean Annual Rainfall*	0.8
Elevation	0.8
Soil Moisture Deficit*	0.8
Slope	0.5
Land Use Intensity	0.3
Aspect	<0.05 (very low)

*adjusted for slope and aspect.

It is important to note that this analysis did not assess erosion risk or attempt to predict sediment loss. Instead, it asked a simpler question: given what we know about the landscape from modern datasets, which combinations of variables best explain where past surveys placed soil types and geological units? In this context, the S-PAL Regolith Classification performed well, despite being developed independently of those legacy maps.

Perfect alignment between S-PAL Regolith Classification and older maps is neither expected nor necessary. Historical soil and geology maps were developed at regional scales and are not designed

to identify small-scale variation within hillslopes or catchments. Features such as localised instability, subtle transitions between rock types, and small patches of different rock or soils fall below their resolution. In contrast, the data sources used to construct S-PAL operate at resolutions between 1 and 50 metres, allowing them to detect fine-scale changes within what older maps treat as single units.

An inspection of the S-PAL Regolith Classification also reveals that soil and geology are often transitional, not sharply bounded. Changes occur gradually across slopes, drainage lines, and boundaries between rock and sediment types. When used in conjunction with faults, folds, and a knowledge of rock layering, the S-PAL Regolith Classification helps make sense of this natural complexity. It recognises that land characteristics can vary within a mapped area, and that interactions between different materials, landforms, and geological settings—such as fault zones or breaks in slope—are often where the most meaningful changes occur.

By revealing internal variations in regolith properties, S-PAL does not replace existing geological or soil maps—it complements them. The classification offers a higher-resolution, process-oriented view of the land's surface materials and structure, making it well suited to tasks such as identifying erosion-prone areas, assessing slope stability, or informing infrastructure and land-use decisions. The regional geological context provided by datasets like Q-MAP remains extremely valuable in this process. While S-PAL Regolith Classification was developed independently of geological maps, those maps offer essential insight into deeper structures—such as faults, folds, or lithological boundaries—that help explain patterns observed at the surface. Together, these layers strengthen the ability to interpret how and why different parts of the landscape may be more or less susceptible to sediment generation.

Although land use intensity had limited explanatory power in this analysis, this is not unexpected. Land use does not shape the deep physical structure of the landscape, but it can influence the timing and severity of erosion. For instance, a steep slope or deeply weathered regolith may remain stable for long periods—until vegetation is removed, water tables shift, or surface conditions are disturbed. In this way, S-PAL provides a structural baseline, while land use influences the likelihood that this inherent susceptibility is expressed.

In summary, this assessment shows that the S-PAL Regolith Classification captures broad patterns in soil and geology, while also providing a finer level of detail and a focus on underlying landscape processes. It offers a different perspective to older mapping layers—one that is based on surface form and material properties, rather than mapped units alone. This makes it a useful input for erosion management, land planning, and environmental assessment, particularly where an understanding of how the land responds to pressure or disturbance is required. A more detailed description of the testing and methods is provided in the Appendix (Technical Information).

9 Validation of S-PAL Susceptibility: How Well Does It Match Real-World Erosion?

To evaluate how well the S-PAL Susceptibility Classification reflects real-world patterns of land instability, a validation study was undertaken by a geology graduate student from the University of Otago, employed as a summer intern by Land and Water Science in 2020. The project was jointly funded by Northland Regional Council (NRC) and the Forest Owners Association of New Zealand.

The study involved scanning satellite imagery to identify visible signs of erosion and slope instability across a wide range of landscapes in Northland. Nearly 1,200 individual features—including slips, slumps, surface erosion, and other forms of sediment movement—were identified and recorded.

Each feature was assigned a severity ranking (low, moderate, or high) and weighted by area to allow fair comparisons across zones of different size. Classifications followed the internationally

recognised standards for erosion and mass movement (e.g. Varnes, 1954; Lynn et al., 2009). The analysis accounted for both the scale (area) and energy (movement type and failure mechanism) of each feature to avoid over-representing any one process.

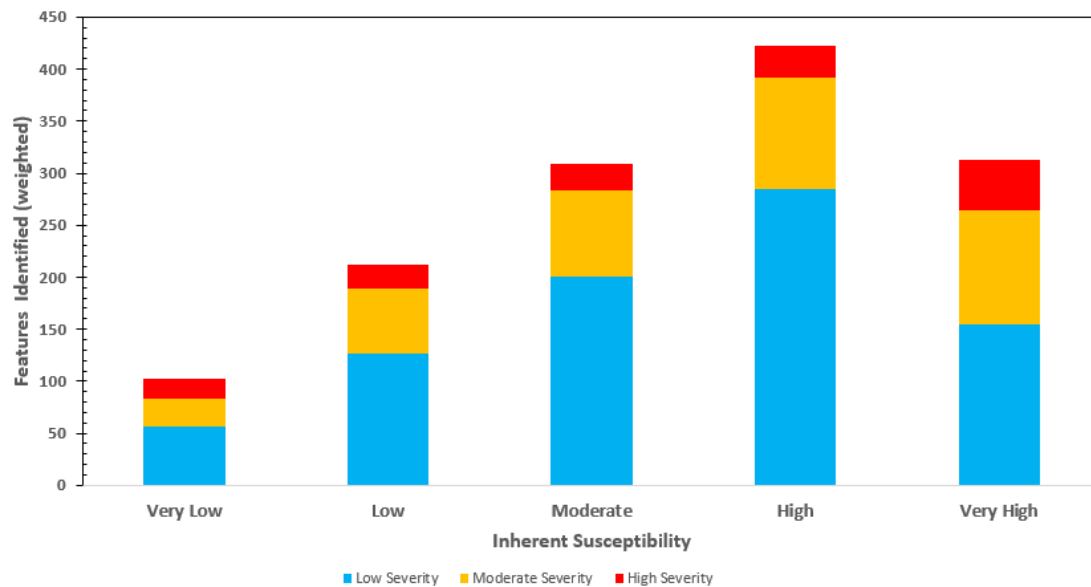


Figure 14 Severity of observed erosion and slope instability features by inherent susceptibility class, as defined in the S-PAL framework.

The figure shows a clear trend—higher susceptibility classes contain more features, and more severe ones.

The results showed a clear and consistent relationship between the S-PAL susceptibility classes and the severity of observed erosion features. As inherent susceptibility increased from ‘Very Low’ to ‘Very High’, so too did the number, size, and energy of the features identified:

- **High and Very High susceptibility classes** contained the greatest number of moderate and high-energy features. In fact, over 50% of all features in the Very High class were ranked moderate or high severity—suggesting that these areas are not only more unstable, but also more likely to generate damaging forms of slope failure.
- **Very Low and Low susceptibility classes** had fewer features overall, and those present were typically lower in severity—mostly minor surface erosion or slow-moving soil creep.

These relationships are not just statistically robust—they align with known principles. As susceptibility increases, both the likelihood and potential impact of slope failure generally rise. However, it is important to avoid the assumption that high susceptibility zones are defined only by large, dramatic mass movement events.

In reality, landscapes with elevated inherent susceptibility often exhibit a wide range of activity—from major landslides and deep-seated slumps to lower-energy processes such as shallow slips, soil creep, small-scale slumping, and **saturation-excess overland flow**. These smaller features:

- Frequently coexist alongside larger failures within the same terrain unit
- May occur more often, even if individually less impactful
- Often signal ongoing regolith adjustment in structurally weak, saturated, or weathered terrain

This is consistent with a continuum rather than a single mode of failure. The presence of many low-severity features in High susceptibility zones, as noted in the analysis, likely reflects this dynamic. These are not outliers—they are a characteristic expression of unstable terrain, particularly in landscapes where regolith is thin, water movement is active, or disturbance is incremental.

By contrast, in Very Low and Low susceptibility areas, the relative absence of both large and small features supports the interpretation of these areas as more stable under current conditions. However, it's also worth noting that some low-severity features may be under-represented in flatter or densely vegetated areas, where they are more easily obscured or rapidly revegetated, especially in plantation or native forest.

The validation used a randomly selected sample of observation points, which helps reduce potential bias related to land use or landscape setting. Still, one limitation remains: not all historic features could be confidently scored for severity, particularly in forested areas where past failures have been masked by regrowth. This likely means that some high-energy features were missed in those areas, although the general trend remains clear.

The results of the validation indicate a clear relationship between S-PAL susceptibility classes and the type and severity of erosion features observed in the landscape. Higher susceptibility classes generally contained a greater number of moderate- to high-severity features, while lower susceptibility areas exhibited fewer features, most of which were low in severity.

For example, although the High susceptibility class contained the largest total number of features, many of these were low-energy processes such as soil creep or shallow slips—particularly in steep but vegetated terrain. In contrast, Very High susceptibility zones—while smaller in area and often located under forest canopy—were associated with a higher proportion of major failures, such as deep-seated slumps or large-scale landslides.

This distribution is consistent with expectations based on landscape process theory. It reflects how slope angle, material strength, weathering, and hydrological conditions interact to influence mass movement behaviour across a range of intensities. The presence of both high- and low-severity features within the same susceptibility class highlights the diverse expressions of instability that can occur within similar regolith settings.

It is also worth noting that the ability to detect and categorise erosion features was not uniform across all land cover types. In forested or densely vegetated areas, some older or less distinct features may have been missed or could not be scored for severity with confidence. This means the recorded distribution likely underestimates the true number of high-severity features in some zones, particularly those with extensive canopy cover.

Despite these limitations, the observed trend is consistent across the dataset: as inherent susceptibility increases, so does the likelihood of encountering more severe erosion features. This supports the broader interpretation that the physical and structural properties of the regolith—and the processes acting on it—play a significant role in shaping where and how erosion occurs.

9.1 Linking to Water Quality Outcomes

One of the primary aims in developing the S-PAL Regolith and Susceptibility Classifications was to improve understanding of how erosion-prone landscapes influence water quality, and to help identify areas where these effects may be most pronounced (Rissmann & Pearson, 2020; Pearson et al., 2020).

To explore this, Northland Regional Council (NRC) commissioned a series of investigations examining how well the S-PAL classifications explain differences in surface water quality across the region. This work formed part of a broader effort to understand how terrain, geology, and soil properties relate to observed patterns in water quality, particularly those linked to erosion and sediment movement (Rissmann & Pearson, 2020; Pearson et al., 2020).

Measured water quality data were sourced from 67 long-term State of Environment (SOE) surface water monitoring sites distributed across Northland. The focus was on indicators that are commonly influenced by erosion processes and sediment transport. These included turbidity (a measure of

water cloudiness), total suspended solids (TSS), water clarity, **total Kjeldahl nitrogen (TKN)**, and particulate phosphorus (PP).

To examine the relationships between landscape characteristics and water quality, a statistical technique called regression modelling was used. This approach estimates how well different combinations of factors—such as land use, rainfall, geology, soil type, and the S-PAL classifications—can help explain variations in the observed water quality data.

To check the reliability of these models, a method known as cross-validation was applied. This involves testing the model on different subsets of the data to see which predictors are consistently useful, and to reduce the chance that results are due to random variation.

Across the models developed for sediment-related indicators, the S-PAL Regolith and Susceptibility Classifications were among the most frequently retained predictors. This means that, in many cases, areas classified as more erosion-prone in the S-PAL mapping framework were associated with higher levels of sediment and related nutrients in downstream monitoring sites.

It is important to note that the S-PAL classifications were developed without reference to the water quality data used in this analysis. Nonetheless, the patterns observed suggest a correspondence between mapped erosion susceptibility and downstream water quality conditions. These findings do not establish cause and effect, but they do indicate a consistent spatial association.

9.2 Applying S-PAL for Soil Conservation and Catchment Planning

Building on the validation studies described above, the S-PAL classification is now being used in practical ways to support land and water management across the region (Pearson et al., 2022). In 2022, it formed the foundation of Northland’s soil conservation strategy, where it was combined with other datasets to identify erosion ‘hotspots’ and prioritise catchments for intervention. The study reinforced that erosion risk is shaped not just by slope but by the underlying geology—especially in areas with weak sedimentary rock. This work is a clear example of how the S-PAL Regolith and Susceptibility Classification can be applied to guide targeted conservation efforts and support more informed decision-making on the ground.

10 Limitations of the S-PAL Framework

While the S-PAL Regolith and Susceptibility classifications provide useful insight into the regolith’s underlying predisposition to erosion, it is important to be clear about their limitations and the context in which they should be interpreted.

The S-PAL Susceptibility Classification represents inherent susceptibility—meaning it reflects long-term, natural characteristics of the regolith that make it more or less prone to instability. It does not measure current erosion rates or account for active land use, land cover, or existing mitigation measures. For this reason, areas identified as highly susceptible may not be actively eroding if well managed, while areas of moderate susceptibility could experience erosion if disturbed or exposed to extreme weather events. The S-PAL Susceptibility Classification describes potential, not realised outcomes.

Land use is intentionally excluded from the classification. This allows S-PAL Susceptibility Classification to act as a consistent baseline, but it also means that land management practices, infrastructure development, and vegetation cover are not reflected in the susceptibility ratings. As a result, the tool should be interpreted alongside up-to-date land use information and field-based knowledge when informing planning or management decisions.

The S-PAL Regolith and Susceptibility classifications are derived from static datasets, including LiDAR and airborne radiometric survey data. These datasets are not updated in real time, and S-PAL does

not respond to recent changes such as land development, natural disturbances, or recent erosion events. It is therefore not suited to short-term forecasting or real-time risk assessment.

While the spatial resolution of S-PAL (typically 25 m) is relatively fine compared to traditional mapping layers, it may not capture very localised features—such as small slips, rills, or gully heads—particularly in heterogeneous terrain. Likewise, the 50 m resolution of the radiometric dataset may limit the detection of fine-scale variability in geochemistry or regolith composition in some settings.

Subsurface conditions—such as detailed regolith profiles, the depth and degree of rock weathering, and structural discontinuities—are not directly measured in the S-PAL. However, the surface signals used in the model (e.g., terrain form, geochemistry, and spectral patterns) are strongly and consistently aligned with mapped geological features such as rock type, faults, folds, and rock layering (stratigraphy). As a result, the influence of deeper structures is often clearly expressed in the spatial patterns within the S-PAL Regolith and Susceptibility classifications, particularly in relation to mass wasting and erosion processes. While the model does not explicitly map subsurface properties, these structural controls are reflected in the classification through their surface expression. For applications requiring detailed subsurface resolution—such as engineering design or site-specific consenting—ground-based investigations should still be used to supplement the broader spatial insights provided by the S-PAL Regolith and Susceptibility classifications.

Finally, the combined S-PAL Regolith and Susceptibility classifications are a regional classification tool. While it can support planning and prioritisation at broad scales, it should not be relied upon in isolation for property-scale decision-making or compliance-related assessments. Interpretation should be informed by local knowledge, field observation, and complementary datasets.

Taken together, these limitations do not reduce the utility of S-PAL Regolith and Susceptibility classifications when used appropriately. Rather, they clarify the model's scope and reinforce the need for complementary inputs when assessing erosion risk or planning land-based interventions.

11 Summary

This report was created for people across Northland—farmers, council staff, iwi and hapū, community leaders, and planners—who want to better understand a new regional tool called the Sediment–Process Attribute Layer, or S-PAL. S-PAL does not replace older soil or geology maps. Instead, it builds on those valuable foundations by adding a new layer of information made possible through modern datasets.

Northland's landscape is complex. Ancient rocks, deeply weathered soils, and long-active fault lines all influence how the land behaves—particularly during heavy rainfall or when disturbed. These natural features shape the land's inherent vulnerability to erosion and slope failure, but until recently, they have been difficult to map in a consistent and spatially resolved way.

S-PAL helps address that gap. It uses high-resolution terrain data (LiDAR) and airborne gamma radiation sensing (AGRS) to describe how the land's shape and surface chemistry relate to its underlying susceptibility to erosion and mass movement. The tool identifies areas where slips, slumps, and sediment detachment are more likely to occur—not based on current land use, but on the land's structure, geology, and weathering history.

It is important to note that S-PAL does not incorporate land use, vegetation cover, or mitigation works. It reflects the underlying sensitivity of the landscape—not actual erosion activity. As such, it highlights where erosion could occur if the land is disturbed, rather than where it is happening now. This distinction makes S-PAL suitable for long-term planning and landscape-scale prioritisation, rather than for real-time or reactive risk management.

The model does not directly measure subsurface conditions such as rock strength or regolith thickness. However, the terrain and radiometric signals it uses are often aligned with deeper

structural controls, including faults, folds, and rock type. These influences are frequently reflected in the spatial patterns observed in the S-PAL outputs and contribute to how susceptibility is distributed.

Because S-PAL is based on regionally consistent datasets, it can be applied across multiple scales—from broad regional screening to property-level decision-making. Its resolution (approximately 0.25 hectares) supports planning at the sub-catchment or farm scale, but may not detect fine-scale or highly localised erosion features. For site-specific assessment or engineering design, additional field investigation remains essential.

This report outlines why parts of Northland are particularly susceptible to erosion, describes how the S-PAL model was constructed, and details the datasets involved—including LiDAR, radiometric inputs, and validation against mapped erosion features. It also examines the geomorphic drivers of erosion, from gradual surface processes to more sudden mass movements. Importantly, S-PAL captures not only slope, but also the broader structural, geological, and chemical context that shapes how the land responds to environmental stress.

While it is not a forecasting tool, S-PAL provides a way to classify and visualise the land's inherent susceptibility to erosion. When used alongside land use information, practical experience, and local knowledge, it can help inform decision-making and support more targeted erosion control. Similar landscape-based approaches are now being developed in other parts of Aotearoa New Zealand to better match mitigation efforts to the physical characteristics of the land.

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14 Appendix – Technical Information

14.1 Assessing the Value of Modern Landscape Data in Explaining Soil and Geology

Understanding how soils and rocks vary across the landscape—and what drives those patterns—is central to land and sediment management in Northland. This study set out to test which environmental factors most strongly influence those patterns and to assess the performance of the Sediment–Process Attribute Layer (S-PAL), a new classification developed specifically for the region.

S-PAL is not a typical map layer. It is a data-driven classification, developed by combining high-resolution terrain information from LiDAR with airborne radiometric data that describes the geochemical character of the land surface. But importantly, S-PAL is not just statistically generated—its structure is grounded in geological reasoning. It reflects expert-informed groupings that align with an understanding of geological processes and controls, landforms, and how these materials interact. These classes are designed to represent functional units in the landscape: zones where the combination of terrain, geology, and geochemistry influences how soils develop and how sediments move.

This analysis aimed to corroborate whether S-PAL is a strong predictor of observed patterns in soils and geology—those captured in regional-scale classification systems—by comparing it with more conventional predictors like terrain, climate, and land use.

14.2 Predictors and Targets

We generated a dataset of 7,500 random locations across Northland. At each point, we extracted the following predictors:

Terrain (LiDAR)

- Elevation (metres relative to sea level, RSL) from 1 m LiDAR
- Slope (degrees)
- Aspect (direction the slope faces)

Climate (Land Environments of New Zealand, LENZ)

- Mean Annual Precipitation (residualised to remove terrain bias)
- Soil Moisture Deficit (residualised)

Radiometrics (New Zealand Petroleum and Minerals, NZP&M)

- Radiometric principal component 1, a composite measure derived from potassium, uranium, thorium, and their ratios

Land Use (Physiographic Environments of New Zealand, PENZ)

- Land Use Intensity (residualised to remove topographic effects)

S-PAL Class

These predictors were tested against established soil and geological classifications:

- Soil type (**NZSC**) and Soil Series (**SERIES**) – Fundamental Soil Layer (1:63,000) (MWLCR)
- Geological Units (**CODE**), dominant (**MAIN_ROCK**), and subordinate (**SUB_ROCK**) rock types, and rock groupings (**ROCK_GROUP** and **ROCK_CLASS**) - Q-MAP (1:250,000) GNS Science

These classifications were the response variables—the outcomes we aimed to explain.

14.3 Analytical Method

We applied some pre-treatment to the data to make sure we could clearly understand which factors were truly influencing soil and rock patterns. Some variables, like climate and land use intensity, are naturally influenced by terrain—for example, rainfall often increases with elevation, and land use tends to be less intensive on steep slopes. To prevent this overlap from confusing the results, we used a process called residualising. This means we removed the part of a variable (like rainfall) that can be explained by another (like elevation), so we could isolate just the effect of rainfall itself. It's like stripping away the influence of terrain so we can see the clean, independent signal from climate or land use.

Radiometric data, which included multiple closely related measurements (like potassium, uranium, and thorium), was summarised using a method that combines them into a few key 'summary axes' or patterns. This process, called principal component analysis, helps reduce clutter in the data while keeping the most important differences.

We then used a method called bootstrapped random forest modelling to work out which variables were the most useful. This technique builds hundreds of decision trees—simple models that try to split the data into logical groups—and it does this many times using different random samples of the data. By repeating the process over and over, we get a much more reliable picture of which variables consistently improve the ability to explain soil or geological types. This approach is especially good for messy, real-world datasets like this, where many variables can interact in complicated or non-linear ways.

14.4 Ensuring Model Reliability

To make sure our results were robust and not simply a product of overfitting or statistical noise, we used two well-established validation methods: cross-validation and out-of-bag (OOB) testing.

Cross-validation works by dividing the dataset into multiple parts and repeatedly training the model on some parts while testing it on others. This helps check whether the model's results are consistent and reliable across different subsets of the data. We used a version called stratified cross-validation, which ensures that all classes (such as different soil or rock types) are fairly represented during each round of testing.

Out-of-bag (OOB) testing is a built-in feature of random forest models. As each decision tree is built, it leaves out a random portion of the data. The model then tests its accuracy on those left-out points. Because this happens many times across all the trees in the forest, OOB testing provides an independent, unbiased estimate of how well the model performs overall.

Together, these two methods helped confirm that the rankings of predictor importance—particularly the strength of S-PAL as a predictor—are reliable and not simply a result of chance or data imbalance.

14.5 A Note on Target Data Limitations

It is important to clarify that this analysis is not intended to create predictions or generate maps. Instead, it was designed to test how well various environmental datasets, including S-PAL, explain patterns seen in existing mapped classifications—soil at approximately 1:63,000 and geology at 1:250,000 scale. These classifications are not designed for paddock- or property-scale use. Their coarseness means that many subtle but important signals—like microclimatic differences due to slope direction, or narrow lithological transitions—are not captured.

That limitation belongs to the response data, not to the predictors. In contrast, S-PAL is resolved at scales appropriate for property-level understanding. This analysis simply assesses whether S-PAL captures the major structural and compositional patterns reflected in New Zealand's regional to national scale classification systems.

14.6 Results

The analysis confirmed that S-PAL was the strongest single predictor of soil and rock classifications across the board. It contributed more explanatory power than any other variable, with a combined total predictive strength of over 2.2 across all response types (Table 3 and Fig. 16).

The next most influential predictor was radiometrics, reflecting the geochemical signature of the land surface. This was followed by Mean Annual Precipitation, Elevation (m RSL), and Soil Moisture Deficit, which were especially important for explaining soil series and NZSC categories.

Slope and Land Use Intensity made modest contributions, while Aspect was the weakest predictor—likely due to its influence being too subtle to appear in broad-scale classification systems.

Table 3 The predictive power of modern datasets

Predictor	Total Predictive Power
S-PAL Class	2.2
Radiometrics	1.0
Mean Annual Precipitation	0.8
Elevation (m RSL)	0.8
Soil Moisture Deficit	0.8
Slope (degrees)	0.5
Land Use Intensity	0.3
Aspect	<0.05

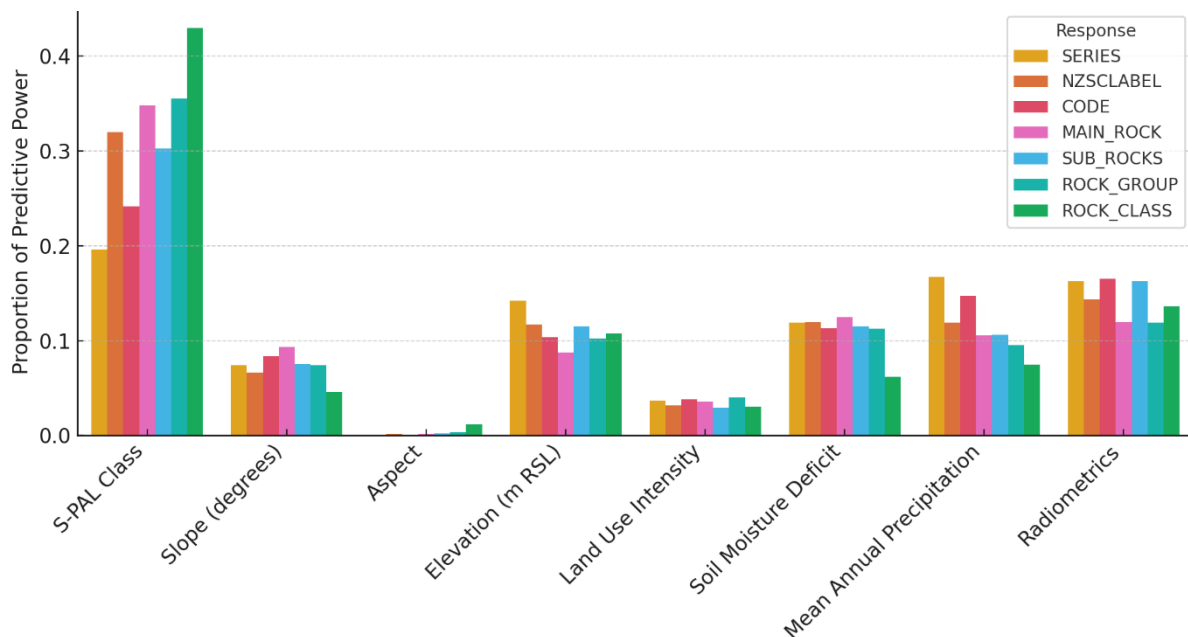


Figure 15 Relative importance of environmental variables in predicting soil and geology classifications

This graph shows the strength of each dataset in predicting soil and geological classes. S-PAL was the strongest individual predictor, with an importance score over 2.2. Radiometric data, Mean Annual Precipitation, Elevation, and Soil Moisture Deficit also contributed meaningfully. Slope and Land Use Intensity had lower predictive value, while Aspect was the least influential.

14.7 Interpretation and Implications

This statistical testing further validates the S-PAL classification. It demonstrates that S-PAL clearly captures the dominant patterns that drive landscape variation across Northland, and that it aligns more closely with mapped soil and geological features than any other single environmental dataset tested. Its strength lies in the way it combines high-resolution terrain structure and surface geochemistry through a geologically informed classification logic—rather than treating these as separate or statistically independent layers.

The moderate but consistent performance of radiometric data and climate variables reinforces their recognised roles in soil and rock development. These factors influence parent material composition, chemical weathering, and the movement and retention of moisture—critical processes in both soil formation and landscape evolution.

In contrast, land use intensity showed relatively low predictive power in explaining the mapped soil or geological classifications. This is not surprising. While land use reflects human activity—such as vegetation clearance, cultivation, or infrastructure development—it does not control the formation of soils or geological substrates, nor the inherent susceptibility of a landscape to erosion. That susceptibility is the product of deep-time processes—terrain formation, lithological structure, and long-term geomorphic shaping—that predate human influence.

However, it is essential to distinguish between inherent susceptibility and actual disturbance. Although land use is not a strong predictor of soil or rock type, it remains the primary agent driving disturbance to the land surface. It is through land use—regardless of its form—that these natural vulnerabilities are activated and mobilised into sediment loss. In other words, land use doesn't determine where the land is weak, but it determines whether that weakness is exposed and expressed.

This distinction explains why land use was ranked lower in the model, yet remains critically important in practice. It interacts with the landscape's pre-existing predisposition, often accelerating

erosion or destabilising systems that would otherwise remain intact. The very low influence of aspect (slope direction) also aligns with expectations. While aspect can affect microclimates or local moisture conditions, those effects are generally too fine-scaled to be captured in regional soil and geological classifications, which generalise over much broader areas.

Overall, these findings confirm that the environmental variation captured by S-PAL closely matches real-world differences in soils and geology, even when compared against coarsely mapped classification systems. The analysis supports the view that S-PAL's process-based structure—integrating surface form, sediment behaviour, and geochemical properties—is a more responsive and representative framework for understanding land characteristics than any one input variable on its own.

14.8 Conclusion

This study indicates that the S-PAL framework provides a regionally consistent representation of landscape structure and associated erosion susceptibility. The model performed well in statistical comparisons with traditional datasets, particularly in its ability to account for spatial variation in soil and geological classifications. While the target classification layers are themselves coarse and not intended for detailed site-scale interpretation, S-PAL appears to offer finer-grained spatial context that reflects underlying environmental drivers. These results suggest that S-PAL may have utility as a supporting input for land evaluation, sediment risk modelling, and regional environmental planning—provided it is used alongside complementary datasets and expert judgement.

14.9 Glossary of Technical Terms and Abbreviations

Airborne Gamma-Ray Spectroscopy (AGRS)	A survey method that uses aircraft to measure natural radiation from the ground. It helps identify different types of soil and rock based on their mineral content. GRS helps map geology, soil properties, and regolith character.
Argillite	A hardened form of mudstone. Although stronger than typical mud, it can still be unstable when weathered or saturated with water.
Basalt	A hard volcanic rock that forms from cooled lava. It often makes up plateaus and ridges.
Bedrock	The solid rock layer beneath soil and loose sediment.
CODE	Refers to Q-MAP Geological Codes, used to identify specific geological units. Each code represents a type of rock or sediment and its geological age, providing a standard way to classify and compare geology across regions.
Creep	A slow, steady form of mass wasting where soil or rock gradually moves downhill.
Depositional landscape/ zone	An area where sediment accumulates rather than being eroded or transported away. These zones typically occur in low-lying or flatter parts of the landscape.
Domain	Broad regolith group based on overall landform shape (e.g., steep hill, flat plain).
K%/ eTh / eU	Abbreviations concentrations of Potassium (%), equivalent Thorium, and equivalent Uranium, respectively. These values are derived from gamma radiation measurements collected by airborne radiometric surveys and are not direct chemical concentrations. The “e” denotes that these are inferred or “equivalent” estimates based on spectral data.
Dispersion	When soil particles (especially clay) break apart and spread out in water. Dispersive soils are more likely to erode when wet.
Drainage system	The network of streams, rivers, and other channels that carry water through a landscape toward a common outlet.
Erosion	The process of soil, sand, or rock being worn away and carried off by wind, rain, or flowing water.
Erosion zone	An area where the rate of sediment loss (through erosion or mass wasting) is greater than the rate of sediment accumulation.
Family	A group of areas within a Domain that share similar underlying rock or sediment types, like basalt or sandstone.
Fault line (or fault)	A crack in the Earth's crust where rock has shifted. Faults create weak zones that are more likely to slip or collapse.
Folds	Bends or warps in layers of rock caused by pressure over geological time. Folds can influence slope shape and instability.
Fundamental Soil Layer (FSL)	A national database that categorises New Zealand soils based on features like type, erodibility, and drainage.

Geological structure / geostructural setting	The arrangement and features of rock layers below the surface, including faults, folds, and contacts between different types of rock. These influence how stable or unstable the land is.
Greywacke	A tough, grey sandstone found in many parts of New Zealand. It's strong overall but can contain weak areas, especially when mixed with other rock types.
Gamma Ray Spectroscopy (GRS)	A remote sensing technique that measures natural gamma radiation from the Earth's surface, primarily from potassium (eK), thorium (eTh), and uranium (eU). GRS data are used to map surface geochemistry and infer soil, rock type, and weathering—supporting erosion and stability assessments.
K-cycle (Butler's K-cycle model)	A theory about how hill country landscapes in New Zealand evolve over time, mainly through slope failure and mass wasting rather than just river erosion.
Landslide	A fast movement of soil or rock down a slope, often triggered by heavy rain or earthquakes.
Light Detection and Ranging (LiDAR)	A laser-based tool that creates detailed 3D maps of the ground surface. It helps identify fine-scale features like slips, ridges, and drainage channels—even under vegetation.
Land Use Capability (LUC)	A system used in New Zealand to classify land based on its ability to support different types of land use without long-term degradation. It incorporates factors like slope, rock type, and erosion risk.
Median Absolute Deviation Z-score (MADZ)	A statistical method used to identify potassium anomalies by comparing local potassium values to regional patterns. High MADZ values indicate active erosion areas, while low values reflect stable or depositional surfaces.
Mass wasting	The movement of soil or rock down a slope due to gravity. Includes slips, landslides, rockfalls, and slow soil creep.
Mélanges	Geological formations made up of a chaotic mix of rock types of varying sizes and origins, typically formed in tectonically active zones such as subduction margins. Mélanges often contain weak, sheared materials and are commonly associated with slope instability and complex ground conditions.
Mudstone	A soft, fine-grained sedimentary rock that is easily weathered and often unstable, especially when wet.
New Zealand Soil Classification (NZSC)	A national system used to group and describe soils in New Zealand based on their physical and chemical characteristics. It assigns soils to categories such as order, group, and subgroup—using names like <i>Typic Orthic Brown Soil</i> —to help identify soil types, their origins, and their suitability for different land uses.
Northland Allochthon	A widespread geological unit in Northland made up of weak sedimentary rocks that are especially prone to erosion.
Northland Regional Council (NRC)	Regional authority responsible for environmental management and land–water planning in Northland.

Out-of-bag testing (OOB)	An internal validation method used in ensemble models like Random Forests. It evaluates model accuracy using the subset of data not included in each bootstrap sample (the 'out-of-bag' data), providing an unbiased estimate of prediction error without needing a separate validation set.
Overland Flow Layer (%OLF)	A spatial dataset representing areas where water flows across the land surface before entering streams or rivers. It is used to identify potential runoff pathways, sediment transport routes, and hydrological connectivity across the landscape—especially during rainfall events.
Pore pressure	The pressure of water in the tiny spaces between soil or rock particles. High pore pressure can reduce friction and lead to slope failure.
Q-MAP	A national geological map dataset produced by GNS Science, showing the type and age of rock formations across New Zealand. It shows the distribution, type, and age of rock and sediment units, helping to describe the geological makeup of a region.
Radiometric data / Radiometric survey	Data collected by measuring natural radiation from the ground. It helps map soil and rock types based on their mineral content.
Regolith	The layer of loose, weathered material—such as soil, gravel, and broken rock—that lies above solid bedrock.
Regolith classification	Grouping different types of regolith based on features such as texture, mineral content, weathering, and susceptibility to erosion.
Rilling	The formation of small, narrow channels (rills) on the soil surface caused by the concentrated flow of runoff during heavy rainfall. It represents an early stage of water erosion and can lead to more severe soil loss if left unmanaged.
Runoff	Water from rain or snow that flows over the land surface, especially after heavy rainfall. It can carry soil and sediment into streams and rivers.
Sandstone	A sedimentary rock made primarily of sand-sized particles. It is usually more resistant to erosion than mudstone but can still become unstable when heavily weathered.
Saturation-excess overland flow	Runoff that occurs when the soil has reached its full water-holding capacity and can no longer absorb additional rainfall. Like an over-soaked sponge, the excess water flows over the surface because the soil is already saturated.
Sheet wash	A shallow, unchannelled flow of water that moves across the ground surface during heavy rainfall, often carrying fine sediment downslope.
Sibling	A group of areas within a Family that have similar surface material properties—such as regolith thickness, texture (e.g. sand vs clay), or age (how weathered it is).
Slope failure	A general term for when a slope becomes unstable and part of it breaks away or collapses.
Soil map	A map showing the distribution and types of soils in an area, usually based on surface characteristics.

Stratigraphy / Stratigraphic layering	The stacking or layering of different rock types over time. Where hard rocks sit on top of soft ones, the lower layers can weaken and lead to instability.
Susceptibility	The likelihood that a particular area will experience erosion or mass movement.
Sediment Process Attribute Layer (S-PAL)	A mapping tool developed for Northland that combines terrain, geology, and radiometric data to show where erosion and mass wasting are most likely to occur.
Terracettes	Small, step-like ridges or benches that form naturally on steep hillslopes. They result from slow downslope movement of soil and surface materials (soil creep) and are often enhanced by the trampling and movement patterns of livestock such as sheep or cattle. Most commonly seen in pasture and indicate gradual surface instability.
Topography	The shape and features of the land surface, including hills, valleys, and slopes.
Toppling	A type of mass wasting where blocks of rock pivot forward and fall downslope, usually along a steep slope or cliff.
Total Kjeldahl Nitrogen (TKN)	A measure of the total concentration of organic nitrogen and ammonia in a sample. TKN is commonly used in water quality testing to assess nutrient loads and potential for eutrophication.
Tunnel gullying	A form of subsurface erosion where water creates tunnels or cavities beneath the ground, leading to sudden collapse and surface instability.
Weathering Intensity Index (WII)	A geospatial index developed by Wilford (2012) that uses GRS and terrain data to estimate the degree of weathering across landscapes. Can be used as a proxy for landscape stability, with more intensely weathered areas often corresponding to increased erosion susceptibility.