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# Calibrating Handheld Spectrometers Against Laboratory Soil Analysis: A Technical Note on Transfer

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## Abstract

*There is real interest in calibrating handheld spectrometers against laboratory soil analysis right now, and real uncertainty about exactly where it delivers the most value. We pull together the current evidence for calibrating handheld spectrometers against laboratory soil analysis, covering the methodological, practical, governance and cost angles, with an eye on where practice has genuinely settled and where farms and advisors are still largely working it out for themselves. Selective, context-specific adoption looks better supported by the evidence gathered here than either broad rollout or blanket avoidance.*

**Keywords:** Calibrating Handheld Spectrometers Against Laboratory Soil Analysis; Agro-informatics; Precision agriculture; Evidence synthesis; On-farm technology

## Introduction

There is no shortage of enthusiasm for calibrating handheld spectrometers against laboratory soil analysis; what there has been a shortage of, until fairly recently, is field data collected under conditions an ordinary farm would recognise.[1] The present technical note sets out what the evidence currently says about calibrating handheld spectrometers against laboratory soil analysis, where practice has genuinely converged, and where it is still mostly guesswork dressed up as best practice.[2]

Interest in calibrating handheld spectrometers against laboratory soil analysis has grown quickly as the underlying sensing, connectivity and modelling tools have become cheap enough to put on an ordinary farm rather than a research plot -- but that speed has left real variation in how different teams define, measure and report on it.[3]

We write this from the standpoint of someone deciding whether calibrating handheld spectrometers against laboratory soil analysis is worth adopting on their own operation, not as a purely academic exercise, and we come back to that practical question throughout.

## Related Work

The published work on calibrating handheld spectrometers against laboratory soil analysis makes a reasonably convincing case for benefit overall, though that case is considerably stronger for some of its sub-questions than others.[4]

Early work in this area was mostly proof-of-concept -- a handful of plots, one season, a promising result. What has followed since has been slower and more methodical: replication, cost analysis, and a small but growing number of studies that actually track outcomes over several seasons rather than one.[5]

## Methodology and Field Approach

Some parts of the calibrating handheld spectrometers against laboratory soil analysis evidence base are backed by several agreeing field studies; other parts rest on one or two single-site reports whose findings may or may not travel to a different soil type, climate or farm scale.[6][7] Where the evidence is solid, practice has started to converge; where it is not, growers and advisors are still making it up as they go, understandably.[8]

A theme that keeps coming up in the calibrating handheld spectrometers against laboratory soil analysis literature is the gap between what works on a well-resourced demonstration plot and what has actually been shown to hold up on an ordinary working farm with its usual constraints on time, connectivity and cash.[9]

Comparing results across the available calibrating handheld spectrometers against laboratory soil analysis studies is genuinely difficult -- different field sizes, different equipment, different ways of defining success -- so the pooled figures reported in this review are best read as a rough indication rather than a precise number.[10][11]

| Question | Current evidence | Practical implication |
|---|---|---|
| Strength of supporting evidence | Uneven across sub-questions | Weight recommendations by evidence tier |
| Consistency across farms | Variable adoption reported | Local trial before wider rollout |
| Metrics used | Mixed on-farm and lab metrics | Prefer studies with real harvest-outcome data |
| Cost / resource implications | Rarely reported in detail | Assess local cost-effectiveness separately |

Table 1: Summary of key considerations for calibrating handheld spectrometers against laboratory soil analysis.

## Evaluation Considerations Across Studies

Study quality across the calibrating handheld spectrometers against laboratory soil analysis literature is mixed. A minority of the work is properly powered with a real comparison group; a larger share reports results from a single field, a single season, with no formal control -- useful as a signal, but not something you would want to bet a season's income on alone.[12]

How "success" gets measured for calibrating handheld spectrometers against laboratory soil analysis also varies a lot between studies, and a result measured against a lab benchmark is simply not the same thing as one measured against what actually happened at harvest, even when both get described in similar language in the abstract.[13]

## Implementation Considerations

Getting calibrating handheld spectrometers against laboratory soil analysis to actually work on a farm involves more than the core technology: access to the field at the right time, a reliable way to review the data it produces, and a plan for what to do when something looks wrong all matter as much as the underlying method.[14] More than one of the deployments we reviewed stalled not because the idea was bad, but because nobody had thought through these unglamorous logistics before rollout.[15]

How much this costs to run, and how much hands-on support it needs, differs a great deal by operation, and anyone evaluating calibrating handheld spectrometers against laboratory soil analysis should budget for a proper trial period on their own land rather than assuming a number from someone else's trial will transfer unchanged.[16]

| Question | Practical implication |
|---|---|
| Does calibrating handheld spectrometers against laboratory soil analysis need specialised equipment or field access? | Budget for setup and time before relying on it |
| Is there a clear way to review calibrating handheld spectrometers against laboratory soil analysis output regularly? | Define who checks it and how often, up front |
| How will calibrating handheld spectrometers against laboratory soil analysis performance be tracked over a season? | Compare against published figures periodically, not just once |
| What scale of operation is calibrating handheld spectrometers against laboratory soil analysis being considered for? | Smaller operations may do better with a shared or managed service |

Table 2: Practical questions for a farm or cooperative considering calibrating handheld spectrometers against laboratory soil analysis.

## Governance and Data Ownership Considerations

Who is actually responsible for calibrating handheld spectrometers against laboratory soil analysis -- and who gets to see the data it generates -- tends to sit across more than one role on a farm or in a cooperative, and that ambiguity is itself a real barrier: a named person with the authority to sign off, question, or pause use of calibrating handheld spectrometers against laboratory soil analysis was consistently associated with a smoother rollout in the cases we looked at.[17]

Paperwork -- a written record of what was tried, a plan for reviewing it periodically -- is easy to treat as an afterthought next to the technical case for calibrating handheld spectrometers against laboratory soil analysis, but the operations that had this in place before they started tended to have fewer arguments about it later.[18]

| Governance element | Recommended owner | Review interval |
|---|---|---|
| Named lead for the programme | One person, clearly named | Annual |
| Written record / documentation | Farm or cooperative manager | Every 2 years or on change |
| Data-review record | Whoever runs the system day to day | At setup and after any change |
| Outcome review | Farm or cooperative committee | Annual |

Table 4: Suggested governance ownership for calibrating handheld spectrometers against laboratory soil analysis.

## Economic and Resource Considerations

Solid cost analyses of calibrating handheld spectrometers against laboratory soil analysis are still thinner on the ground than the accuracy-focused literature would suggest they should be, and the ones that exist do not agree on how to count the offsetting savings, which makes comparing reported costs across studies harder than it sounds.[19]

Where the budget impact of calibrating handheld spectrometers against laboratory soil analysis has actually been modelled, the upfront cost of kit and setup dominates in the first season or two; ongoing running costs only start to matter once the system has been in use long enough to reach a steady rhythm.[20]

| Cost driver | Typical phase | Notes |
|---|---|---|
| Equipment / platform purchase | Upfront | Often the largest single line item |
| Setup and integration time | Upfront | Frequently under-budgeted |
| Data review / running costs | Recurrent | Scales with area or herd/flock size |
| Support and maintenance | Recurrent | Required for most working deployments |
| Training and onboarding | Upfront + recurrent | Cost often overlooked |

Table 3: Principal cost drivers relevant to calibrating handheld spectrometers against laboratory soil analysis implementation.

## Stakeholder and Farmer Perspectives

Farmers we and others have spoken to about calibrating handheld spectrometers against laboratory soil analysis care less about a raw number than about being told, in plain terms, what to actually do differently -- that distinction shows up again and again in how well a given deployment gets used.[21]

Trust in calibrating handheld spectrometers against laboratory soil analysis builds slowly, over a season or two of watching the tool's output line up with what actually happens in the field, rather than arriving all at once when someone signs up; a short pilot probably understates how well it would land given more time.

## Reproducibility and Standardisation

Independent attempts to reproduce calibrating handheld spectrometers against laboratory soil analysis results are still rare relative to how many claims have been published, and most operations end up re-checking things informally against a neighbour or peer group rather than any shared standard.[22]

Different teams define and report calibrating handheld spectrometers against laboratory soil analysis differently enough that comparing across studies is harder than it should be; agreeing on a shared minimum reporting standard, rather than reconciling everything after the fact, would help a lot here.[23]

## Limitations

A few things temper how far these conclusions about calibrating handheld spectrometers against laboratory soil analysis should be pushed. Much of what we drew on here is observational rather than a proper randomised comparison, so we cannot rule out that something else we did not measure explains part of what looks like a calibrating handheld spectrometers against laboratory soil analysis effect, and studies with a disappointing result are less likely to get published in the first place.[24]

Reporting standards vary enough across the calibrating handheld spectrometers against laboratory soil analysis studies reviewed here that a direct side-by-side comparison of effect sizes should be read with some caution rather than taken at face value.

## Future Directions

What would help most now is not another single-season demonstration of calibrating handheld spectrometers against laboratory soil analysis but a properly multi-site, multi-season trial that reports real farm-level outcomes alongside the usual accuracy figures.[25]

Shared tools and a common reference point for calibrating handheld spectrometers against laboratory soil analysis, where they do not already exist, would narrow a lot of the current variation in practice -- and the people side of this deserves more attention than it usually gets: keeping the expertise once a farm or cooperative has built it up is its own ongoing job.[26]

## Discussion

Put simply, the evidence here favours using calibrating handheld spectrometers against laboratory soil analysis selectively and deliberately, on the operations and situations where it clearly earns its keep, rather than either adopting it everywhere or dismissing it outright. Which side of that line a given farm sits on depends a lot on its own circumstances.[27] A proper multi-site trial would help settle several of the open questions raised above.[28]

None of the cost or governance points raised above change what the underlying evidence says about calibrating handheld spectrometers against laboratory soil analysis itself -- but they do go a long way toward explaining why a technology with decen

supporting evidence does not always translate into steady, reliable use once a farm actually tries it.[29]

This review reflects the literature as it stands today and, inevitably, some judgement calls in pulling together a genuinely mixed evidence base; anyone applying these conclusions on their own land should weigh them against their own soils, climate and resources.

## Conclusion

Calibrating Handheld Spectrometers Against Laboratory Soil Analysis is backed by a real but still uneven body of evidence, strongest in specific, well-defined situations rather than universally so. How well it is implemented, governed and paid for shapes whether that evidence actually translates into steady use on a working farm -- and the honest answer to whether it is worth adopting depends more on the specific context than on any blanket verdict about the technology itself.

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## Conflict of Interest

The authors declare no competing financial or non-financial interests relevant to the content of this review.

## Author Contributions

C.V. conceived the review and drafted the manuscript; G.D. conducted the evidence synthesis and prepared the tables; G.B. contributed the on-farm implementation and cost analysis and revised the manuscript. All authors approved the final version.

All authors read and approved the manuscript in its final form and take public responsibility for its content.

## Ethics Statement

This review synthesises previously published evidence on calibrating handheld spectrometers against laboratory soil analysis and did not involve new data collection from human participants; no separate ethics approval was required.

## Data Availability

No new data were generated for this review; all sources discussed are cited in the References list below.

Worth saying plainly: calibrating handheld spectrometers against laboratory soil analysis rarely gets adopted in isolation. It has to fit around whatever a farm is already doing, and the operations that mapped out how it would slot into existing routines before starting tended to run into fewer surprises than those that treated it as a bolt-on extra.

Comparing your own results for calibrating handheld spectrometers against laboratory soil analysis against a published figure is useful, but do it cautiously -- published numbers often come from better-resourced trials than an ordinary working farm can match.

Making sure knowledge about calibrating handheld spectrometers against laboratory soil analysis does not live in one person's head is a real, if unglamorous, risk that keeps coming up in the implementation literature -- worth planning for before it becomes a problem.

When calibrating handheld spectrometers against laboratory soil analysis has been dropped after an initial trial, the reason given is usually practical -- staffing, cost, or the maintenance burden -- rather than the underlying idea turning out to be wrong.

Rules around calibrating handheld spectrometers against laboratory soil analysis differ enough from one region to the next that anyone operating across borders should expect some friction, and that friction has not gone away despite repeated calls to sort it out.

We simply do not have much long-term data on calibrating handheld spectrometers against laboratory soil analysis yet -- most of what exists is short-term or from a demonstration setting, and that should temper how far anyone extrapolates it.

How new staff get trained on calibrating handheld spectrometers against laboratory soil analysis varies a lot between operations, and a proper structured programme seems to correlate with a smoother transition, though this could partly reflect which operations bother to build one in the first place.

Data handling for calibrating handheld spectrometers against laboratory soil analysis -- particularly where readings or imagery get stored or shared with a third party -- deserves the same explicit attention as the rest of the governance picture, and is easy to overlook early on.

There is a real risk that calibrating handheld spectrometers against laboratory soil analysis ends up concentrated among better-resourced operations, leaving smaller farms without practical access regardless of how good the underlying evidence is.

Choosing between vendors or platforms for calibrating handheld spectrometers against laboratory soil analysis, where there is a real choice to make, gets surprisingly little attention in the published literature given how much it matters in practice.

Revisiting calibrating handheld spectrometers against laboratory soil analysis against an updated baseline every so often is recommended by several of the sources we drew on, but it rarely happens as a matter of routine once the initial set-up work is done.

None of these practical points change what the underlying evidence says about calibrating handheld spectrometers against

laboratory soil analysis -- but they go a long way toward explaining the gap between decent evidence and consistent day-to-day use.

Throughout this piece we have tried to keep the question of whether calibrating handheld spectrometers against laboratory soil analysis works separate from the question of whether it is easy to run well, since conflating the two is, in our view, a common source of both over- and under-adoption.

Where an operation cannot justify the full cost of calibrating handheld spectrometers against laboratory soil analysis alone, sharing it through a cooperative or a managed service looks like a workable middle ground that keeps the door open without the full up-front outlay.

Finally, it is worth revisiting the evidence on calibrating handheld spectrometers against laboratory soil analysis every so often -- this is a fast-moving area, and a fair assessment today may need updating within a few years as more field data comes in.

Keeping spare parts and consumables in supply is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is a single supplier running out at the wrong moment, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on getting the data to talk to whatever software the farm already uses, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is readings arriving in a format nothing else can read, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Having a backup when the one person who understands the system is away deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often the whole thing stalling for weeks over one absence turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Rules that differ from one region to the next is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is different consent or data rules tripping up a cross-border operation, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on making sure people actually know the tool exists, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is a capability sitting unused because nobody downstream was told about it, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Checking in on quality over time, not just at setup deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often drift going unnoticed between the rare formal reviews turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

The environmental footprint of running more hardware is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is the energy or material cost of scaling up going unexamined, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on getting findings to the people who actually decide what happens next, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is useful results arriving too late to change anything, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Comparing against whatever the farm was already doing deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often adoption running ahead of any real head-to-head comparison turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Keeping an eye on it after the initial rollout, not just during it is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld

spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is early performance never being checked again once the novelty wears off, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on making sure people understand what they are signing up for, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is consent being more of a formality than a real understanding, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Access for operations with less spare cash deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often the technology ending up only within reach of the better-resourced farms turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

What else the collected data could be used for later on is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is governance never having anticipated a use nobody originally planned, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on getting locked into one supplier's platform, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is switching provider later turning out to be far harder than expected, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

The extra load on staff during the changeover deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often nobody actually measuring how much harder the transition made everyone's week turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Whether a small trial actually predicts success at full scale is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is a promising pilot simply not holding up once rolled out properly, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on fitting in with whatever the wider farm or business is trying to do, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is the tool being adopted in a vacuum, disconnected from broader plans, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Bringing in the people who will actually use it day to day deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often a system built with no input from whoever ends up running it turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Comparing results fairly as the hardware itself changes over time is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is readings from an old sensor generation being compared directly with a new one, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on having any kind of review scheduled after the initial rollout, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is nobody circling back to check how it actually went, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Who is on the hook if something goes wrong deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often responsibility for a bad outcome being unclear between the parties involved turns up afterward as part of the

explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Competing for the same pot of money as everything else on the farm is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is a genuinely good case losing out to a more urgent-seeming priority, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on everyone using the same words to mean different things, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is confusion simply because two operations define a term differently, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Whether anyone downstream is ready to act on the results deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often a solid finding having nowhere useful to go turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Checking against what neighbouring operations are seeing is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is having no external reference point for whether your own numbers are normal, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of calibrating handheld spectrometers against laboratory soil analysis increasingly touches on the paperwork load this creates for whoever is running it day to day, which reflects a broader shift toward judging new agricultural technology on how well it actually runs day to day, not just on paper. A common failure mode here is admin eating into the time that should go to the actual work, and operations that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

What happens if one key piece of kit fails deserves more attention in any calibrating handheld spectrometers against laboratory soil analysis adoption plan than it usually gets, given how often a single point of failure turning into a bigger problem than it should turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother adoptions from the rougher ones.

Being honest when something did not work is a further practical point relevant to calibrating handheld spectrometers against laboratory soil analysis that gets less attention than the core method itself, yet it matters a great deal for whether an operation can keep calibrating handheld spectrometers against laboratory soil analysis running once the initial enthusiasm wears off. The risk that comes up most often here is a skewed picture building up because only the good results get talked about, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

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