

Time to consider the practicalities of passive seismic acquisition

Bob Heath* casts a critical eye over current passive seismic acquisition equipment and operations and suggests that experience with past new technology evolution in land seismic may offer some valuable lessons and pitfalls to avoid.

Passive acquisition appears to be all the rage. Geophysical societies hold workshops on the theme and many magazine column inches are devoted to it. Some even say that it is the fastest growing sector in exploration. But is this field really ready for the big-time? Is the industry prepared to ‘do passive’ properly to get the most out of it? In some ways, passive only seems to be where active acquisition was at the dawn of the 3D land seismic era: lots of expectation, theories, and ideas but rather less in terms of hardware well suited to the job or an understanding of all the practicalities.

This article is an attempt to convert the theoretical into getting the best from real projects. It discusses how choice of equipment and method of deployment affect passive acquisition today every bit as much as it did for active exploration a quarter century ago, and hopes that some of the same mistakes can thus be avoided.

So what is passive acquisition? At its most recent workshop, the EAGE provided a non-exhaustive list: reservoir monitoring, CO2 sequestration, mining and geotechnical applications, hazards, and geothermal. I would add hazard/safety monitoring, microseismic recording and, as imperfectly defined as it is, the related topic of permanent monitoring

too. Like any new field, terminology is rather messy since there can be overlap between these operations; permanent monitoring projects can be passive operations also. In fact, in some people’s minds, anything which is not out-and-out active exploration comes under the heading of passive and I shall go along with that here.

Passive reality

The potential benefits of recording without controlled sources appear to have taken some by surprise, including even a few oilfield service companies and geophysical contractors. This has led to cases where survey planners have not had time to get to grips with all the practicalities which can determine the operation’s success from both the economic and data quality points of view. After all, whereas there’s a lot of different hardware available, not much of it was designed specifically for the purpose and some certainly is not being used as per the user manual. In fact, devising equipment suited to a set of passive operations, which is far wider than anything encountered in active recording, has been no simple matter.

So let us look at what is necessary to make sure that passive/permanent surveys pay the biggest dividends and as



Passive recording includes mining and hazard evaluation, (Sigma Observer software.)

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Onsite training, Sigma passive operation, Texas 2011.

quickly as possible, and not make the mistake of the early land active recording 3D pioneers who took a decade or more to learn things the hard way.

Specifications

Whereas all geoscientists are happy thinking in scientific terms, the most important unit when it comes to this new field is not velocity or frequency but is the dollar. In the past, passive equipment was often rather expensive to buy, costly to use, and generally designed for a few rather specific tasks. Fortunately, there is now hardware which can be considered 'universal' (able to be used on almost all active and passive operations), prices have dropped and with the right training, can be much lower cost to use too. So before we get too carried away with the details of the technology, the fact that there is a new commercial reality is the first thing we can celebrate.

Many may think that one set of seismic system specifications is much the same as the next, and in active recording hardware there is a good deal of truth in this. A few decibels better here or microvolts there is not going to make much difference on a land crew, especially compared to such simple things as planting the geophones properly. Take a look at the specs of the designed-purely-for-active systems and you might find it hard to fit a cigarette paper between them. This is partly because many manufacturers use the same chip sets and partly because developers know that these figures are accepted as both sufficient for the industry and obtainable with most decent engineers. Why bother with anything more?

In passive recording equipment, specifications and functionality differ between systems far more and these differences can most definitely affect the final result in greater ways than in active recording. Take for example the frequency range of an instrument. While Nyquist's theorem (sample rate) sets the upper limit of recoverable frequency, I know of no hardware which has the slightest difficulty in digitizing the highest frequencies which mother earth deigns

to propagate through the bits of the planet we are generally interested in; so both made-for-active and made-for-passive products serve their causes well here.

Yet when it comes to low frequencies, some hardware limits the response to 3 Hz, which is far from ideal for passive. There can be several reasons for this but generally it is either because few in active seismic care about anything this low, or because most man-made sources do not give out much energy in the long wavelength section of the seismic spectrum. This then engenders the attitude 'if we can't produce it, why make the extra effort to build an instrument which listens for it?'

However, much non-active work not only feels at home with lower frequency but positively excels there. For example, using sensors and instruments which are capable of <1 Hz allows us to tap into passive surface and body waves to image the subsurface geology in a way which active does not. Also, presence of partially saturated hydrocarbon reservoirs is associated with spectral anomalies in the range of 1–6 Hz in microtremors. When measured at the surface, the spectral energy is elevated above a hydrocarbon reservoir compared with spectral energy measured at positions away from a reservoir (1–3.5 or 1–6 Hz) and the spectral ratio between vertical and horizontal components (V/H) can show anomalies in the presence of hydrocarbons. The polarization of the waves might also provide information about the time variability of the microtremor phenomena related to hydrocarbon reservoirs. So any recorder which wants to describe itself as good for passive applications needs to have the functionality to cope with all this.

Let us also consider instantaneous dynamic range. This can be considered as the ratio of the smallest signal an instrument can deal with to the largest one it can simultaneously handle without over-scaling. In active recording many insist on this being as high as possible while devising surveys which then fail to make full use of the range. But in passive/permanent monitoring the first of these values is especially important because such surveys may use sensors deployed in lower noise environments, buried or be part of a downhole tool, whose outputs are made available at the surface. Then passive operations often have to accept high level inputs where sensors output high voltages due to vehicular traffic. There are also some advantages to connecting multiple geophones in series to increase the output of the array. Both extremes of signal must be sampled well at the same time so one can be removed while the other is processed.

Typical 24-bit over-sampling based instruments struggle with this but at least one recorder, Sigma from iSeis, can handle the task as it has a 32-bit convertor with the necessary characteristics. One may thus conclude that when planning a passive rather than an active survey, specifications do make a definite difference.

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There is also a lot of work underway in regard to sensors, both single and multi-component, and so far it seems that the simple analogue variety offers the most benefits to this field. These include their much superior performance especially in terms of noise, the ability to use different recording systems and to be used in arrays, better cost, and robustness. Also, as passive generally requires use of cableless recorders where power is at a premium, any transducer such as a MEMS accelerometer which requires extra power, should also be seen as a distinct drawback.

Extent of operations

Before we go further investigating what other features are important for perfecting passive, we must think about the different sort of environments where these various operations may take place. Few would claim that the average active crew has life easy but compared to the extremes where passive may have to perform, it is definitely active recording which gets the easier ride.

Let us consider the simple areal extent of passive and permanent surveys. Here, the terrain across which deployed equipment may have to be continuously monitored, maintained, and perhaps even provide real time data has already reached hundreds of square kilometres and is only going to

get larger. The most extensive such operation this author is familiar with is about five times larger than the biggest live patch ever switched on for an active land survey. Additionally, passive work often takes place in areas of much higher cultural activity and this presents an extra set of problems in terms both of initial equipment deployment and ongoing operations.

However, it is not just the survey's physical extent or terrain challenges but also the lower average channel density of passive recording and the totally irregular layout patterns which make life awkward. This is because symmetrical geometries and, within certain limits, high channel densities make it far simpler for most hardware to work well nowadays, compared to sparsely or irregularly deployed equipment. Indeed, there are some systems which can only work when the layout is neat and regular. So if we want to perform surveys in wide expanses of tricky terrain with almost random and low channel densities it is clear that our hardware options are going to be limited.

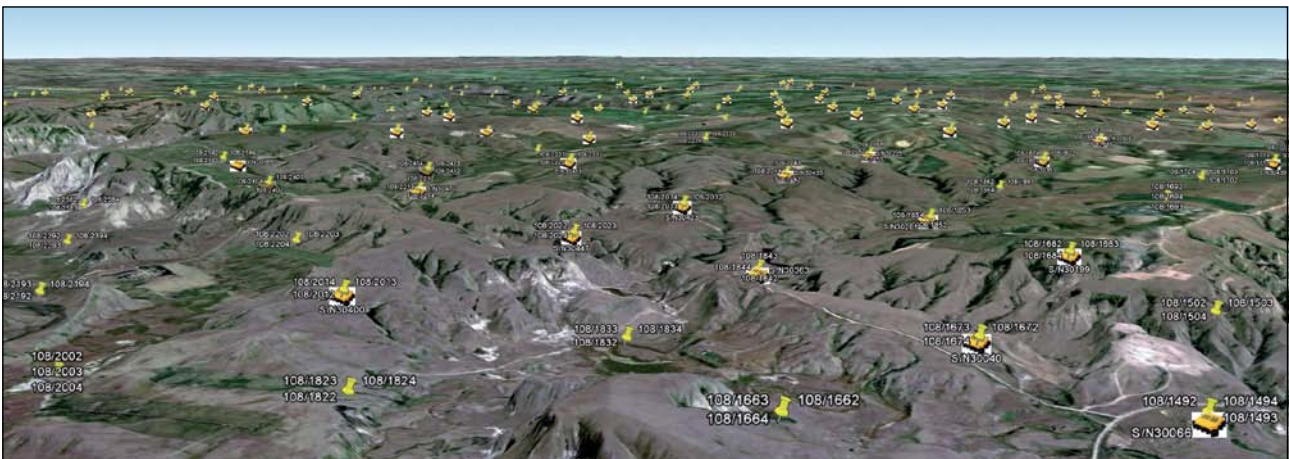
The traditional land market is monopolized by instruments which rely on twisted pair digital telemetry spread cables. Although now stretched to the limit of what they can achieve in engineering terms, cable-based recording has been perfected enough such that logistically simple active surveys



Sensor testing with Wifi pass-by download.



Accidents happen. needs Passive hardware needs to be more robust than active recording hardware.



Very large stationary array over difficult terrain with RTR capability. Google Earth imagery can be used for planning purposes.

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can be undertaken with an amount of drama which most contractors have learned to cope with. And because of cable's dominance, for some it was originally the technology of choice for passive too. But it is obvious that the component which makes such hardware viable in active recording – the spread cable – is what makes it unsuited for routine passive/permanent jobs and thus cabled systems are the first equipment type to drop off the list in this new frontier. In fairness they were never designed for this sort of work so our expectations should never have been too great. That leaves us with cableless, cablefree, or wireless technologies (the terms can be synonymous here) and the features they offer for passive's progress.

Monitoring

So what type of cableless kit is ideal to take on all that passive has to throw at it? That may be easier to answer by considering what is inappropriate. The problem is, while none of these systems by definition rely on cable telemetry, most wireless product developers made no attempt to design in any feature which would allow the smallest amount of data to be returned from remote units deployed across even small survey areas. Such limited hardware, which can also not 'hear' commands from the central system, is often referred to as 'shoot blind'.

For very short-term or limited areal extent passive work this may not be much of a hindrance. But to avoid potential embarrassment elsewhere these shortcomings tend to mark out such equipment as unsuitable. Experience has already revealed that it can be disastrous not to know what is happening 'out there' when operations call for leaving out equipment for days, if not months, or indefinitely. On an active survey it is not considered a luxury to be sure that ground units, power supplies, and sensors are always working properly and neither should it be necessary in passive, where there is no second chance to log an event. Traversing huge areas on foot in inappropriate and noisy vehicles just to assure oneself the job is being done properly is somewhat impractical.

It may be true that shootblind hardware used to be the lower cost route but this is mostly no longer the case. In terms of hardware purchase and even more so in operational savings, 'doing things cost effectively' now means using equipment which can remotely monitor what's going on by use of built-in mesh radio networking (MRN). These MRNs only have to get their 'messages', which include QC, status, and remote control commands, to an adjacent ground unit which then passes them along, disseminating over the entire operation using the licence-free 2.4 GHz band.

MRNs are the opposite of what earlier wireless systems were in land seismic, where they had to transmit the entire width of the spread, requiring lots of power. Even so, off-the-shelf MRN technology in the past was not well suited to some passive operations where channel densities were

especially low. However, through recent enhancements of the protocol and occasionally some judicious use of simple MRN relays, it has become much more passive-friendly. What MRNs offer in terms of communications bandwidth is still rather limited and cannot be used for sending back the full seismic record in real-time. The technology for doing so will be considered later.

Enhanced MRNs are already quite capable of providing remote control functionality and the throughput to monitor large numbers of channels and multiple test functions, such as sensor, GPS reception (which can come and go in some places, which is why it is essential to have some alternative when GPS reception is not available), ground unit i-tests, battery power, and so on. These are all things which the passive operator needs to know. Indeed, some recent operations demonstrated that they are of inestimable benefit to the passive environment. The alternative is to see nothing and keep one's fingers crossed.

If we are still considering systems with no real time recording option, the final issue in this section is how much data storage each ground unit needs; especially taking into account that passive often uses fairly high sample rates. To put some rough figures on this, a single channel sampling every millisecond, operating 24/7 for a month and outputting 4 bytes per sample, plus some overhead, will take up a significant fraction of a 16 GB memory card. A three component survey under the same conditions is going to use up close on 40 GB. Many of us get rather blasé about data capacity as mobile phones with dozens of gigabytes storage are common but some seismic instruments run out of memory address space at 2 or 4 GB. This used to be enough for many types of active survey but clearly not sufficient to take on much else.

Data handling (harvesting)

We have looked at some of the features that passive needs compared to active, and how they impose greatly differing requirements on the hardware and its deployment. It has been seen that cableless systems with high memory capacity and an ability to remotely control/monitor at least system basics are the best tool for the job. We now jump forward a few hours, or days, or months confident that everything has been working well during this time, and realize that we need to get our hands on some of this data. At this stage we assume that if real-time recording is an option offered for that particular cableless system, it was not being used, and we have to go about data collection in some other way.

In active work, equipment fairly regularly gets picked up by the line crew and moved forward. For such surveys using some types of cableless equipment, this is when ground units have to be rounded up in some staging area and data downloaded. Not only does this require more equipment – ground units cannot simultaneously be in harvest mode at some

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Wifi options for real-time recording, long distance transmission capabilities.

central location and recording on the line – but it delays the time at which users get to see some data. If the ground units are limited in storage capacity this presents further challenges to the operator who will have to collect them up merely to download data while deploying fresh boxes in the same place. In permanent and passive, a rule is that accessing the data should not interfere with on-going acquisition and fortunately there are a few cableless systems which do allow data to be downloaded while it is being recorded, thus not messing with the monitoring process.

However, different surveys call for different ideal methods of harvesting so, for greatest efficiency, data security, and HSE

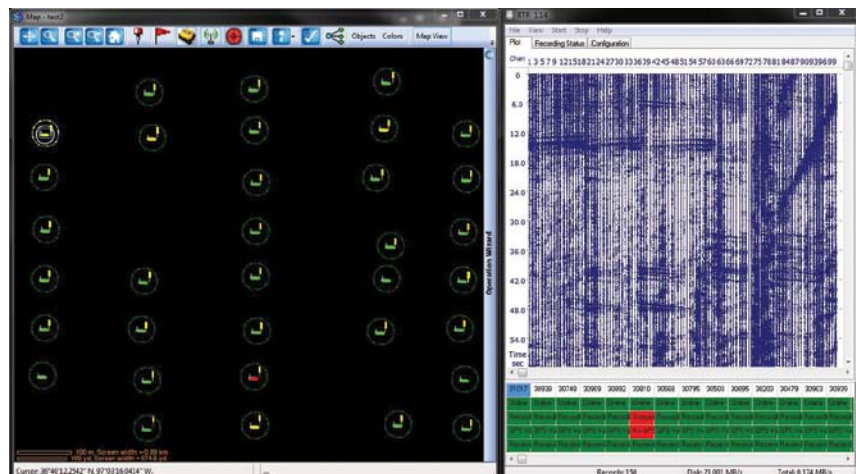
exposure, data collection must be flexible too. Some recorders allow the user to plug a laptop or tablet PC directly into the ground unit and copy the data, while it is still deployed and acquiring data. Some users prefer not to have to carry computers into the field and want to harvest via removable USB stick, also without disturbing acquisition. Both can be accommodated.

Some surveys can be more efficient by not having to touch the ground box at all and make use of internal omni-directional Wi-Fi for transmitting data to the harvesting device as it passes by. The downside of this is that range can be rather limited, and data rate is affected by quality of connection which is in turn governed by range. So the option of an external Wi-Fi, either of omni- or semi-directional design permits further levels of harvesting flexibility which can make all the difference considering passive data volumes and problems of access. As Wi-Fi can be power-hungry, so an MRN is useful to turn on/off the Wi-Fi when it is not needed, thus saving valuable battery energy. Even in something as obvious to exploration geophysics as data collection, we see some major differences between what is acceptable for passive versus active.

Real-time recording

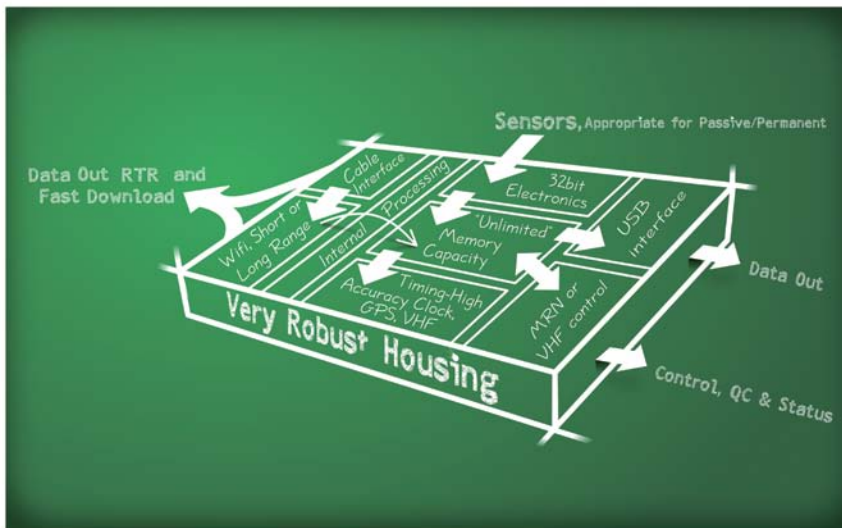
It has been shown that cableless instruments are the only solution to many types of passive/permanent work. But what if the user wants real-time recording (RTR) to be able to sit in some central location, which may even be in a different country and have all data appear before him? The number of cableless recorders with any sort of RTR option can just about be counted on the fingers of one hand. However, almost all of these were designed for active work and may struggle to cope in some passive operations, especially given the low channel density, uneven geometries, and huge survey areas.

Here, the first things to realize is that various types of passive/permanent recording now go on globally, so any hardware which must be useable around the world will have to pay attention to various RF challenges. VHF communica-



Real-time monitoring of deployed hardware and passive data in central location.

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Stylised representation of universal hardware ideal for passive, permanent and active recording.

tion would not be appropriate for the transmission task given power requirements, bandwidth limitations, and licensing difficulties. It seems that the 2.4 GHz band is the only truly licence-free one anywhere on Planet Earth. Of course, this band has its problems such as absorption which only gets worse by going to higher microwave frequencies. 2.4 GHz is the devil we know and it is what must be used to turn a cableless system into an internationally capable real-time recorder.

Here, the same longer range omni-directional external Wi-Fi as used for pass-by downloading can be used for real-time, or something a bit more directional. Using Wi-Fi to control remote equipment and return data is at least 10 years



Use of Wifi for seismic system control and data retrieval, 2001 (SSC archive).

old in the seismic domain. To ensure Wi-Fi connectivity over large distances with irregularly spaced data collectors, more modern technology must be used possibly along with some judiciously placed repeaters. However, the quantity can be fairly low with proper planning. Some systems now even allow Google Earth imagery to find lines of sight. Repeater tower densities as low as one every 20–40 km² may be achievable and even fewer if data can be hopped from station to station.

This is not to say that all passive acquisition which requires real-time recording happens over large distances. The monitoring of fracturing can take place over relatively small areas and here cableless equipment, which has the ability to be hardwired together for the purpose, enables one set of equipment to be easily adapted to take on all RTR roles. Such are the requirements of the ‘universal’ recorder.

Future-seismic

Most who study novel instrumentation and the plethora of new geophysical techniques believe that we are currently in an era of very rapid change. What we may consider as state-of-the-art today almost certainly will become antiquated at a rate few have ever experienced before. Thus the notion of ‘future-seismic’ is something that should be of interest to us all and passive is starting to make its presence felt here too, though not in the way many predicted.

Source control flexibility is one area where future-seismic aficionados have recently started looking resulting in, for example, a new generation of vibroseis controller; active-passive recording is probably next in line. There have already been surveys which used standard hardware to record actively during the day and are then left switched on at night to gather passive data, often with mixed results given the limitations of the hardware used. So can the latest generations of passive equipment help take geophysics further into the future? Clearly, as passive systems have at last surpassed active record-

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Cableless equipment now offers hardwire options as universal system.

ers in specifications and functionality, it may well be time for geoscientists to consider what may be gained undertaking the active-passive job properly, and even more regularly.

Field operations

Although the latest passive equipment may be employed on almost any active or non-active survey, this does not mean that the greatest crew efficiencies come from running all operations in the same way. As different as the ideal passive recorder is now from the generally used active recorder, field operations differ even more.

Active seismic often needs armies of juggies who are there to put down and a little while later pick up geophones and other hardware. Taking a line crew who may be expert at traditional surveys and expecting them to do just as well first time out on a passive operation is a lot to expect. Passive

operations tend to need a small crew of individuals who have been instructed in the essential differences between active and passive operations (system manufacturers should be able to say what these are) and who can also work as a small team. A few jacks-of-all-trades rather than dozens of masters-of-none.

Daily logistics are everything to a passive crew because there is no source crew to manage, thereby controlling the data flow. The data simply arrive every moment of every day whether the crew is ready or not. To cope, battery management should be one of the things at the top of the daily to-do list, not necessarily because of fear of batteries running down – a good system lets you monitor this remotely – but to prevent surprises. And where RTR is not being used, it is good idea to set up a harvesting routine on a daily basis too for the same reason. By using simple spreadsheets to manage logistics, it is possible to increase accountability and avoid equipment-based panics.

The operatives need to be well trained and better equipped, with their own tools and a workshop, which will probably be larger than is found on many active operations with similar channel counts. Workers may also need their own transportation and ideally there should be a ‘field co-ordinator’ as well as a ‘shop co-ordinator’ to run things smoothly. These key people should understand such things as budgeting, procurement, and scheduling in a way which is not usually found on an active crew. This may be an extra expense, and one which will be reduced by using more capable passive hardware, but do not expect to get the best results without such a small core of qualified and properly equipped staff.

Hardware Capability/Feature	Traditional Active	Ideal Passive/Permanent
Cable or cableless system	Either	Cableless essential for most applications
System robustness	Medium	Maximum robustness required
Analog to digital convertor	24 bits	32 bits
Low frequency system limit	3 Hz	< 1 Hz
System dynamic range	Limited	Maximum possible. May have simultaneously to handle low noise and high input from serial sensor arrays
Survey aerial extent	< 200 sq.km	Can be > 1,000 sq.km
Data rate	Low - High	Low - Medium
Continuous recording	Occasionally required	Almost always required
Equipment remote control	Useful but not essential	Mostly essential
Equipment monitoring	Useful but not essential	Essential
Data return real time	Useful but not essential	Essential in some contracts
Download speed	Low-High, intermittent	Low-High, continuous
In-field data harvesting	Useful but not essential	Essential if not real time
Channel density	Medium - High	Low - Medium
Geometry	Usually regular	Usually irregular
System memory capacity requirement	Zero - low	Zero to (functionally) unlimited
Removable storage media	Sometimes useful but not usually available	Very useful
Sensor types	Limited	Large varieties of types, frequencies, sensitivities, configurations, surface and downhole
Data format	SEGD or SEG-Y	SEGD or SEG-Y
Operation Personnel	Usually dependent on large crew of labourers	More dependent on low no's of individual technicians
Operation Duration	Limited	Can be unlimited.
Universal/dual operations	Not possible	Ideal passive/system also good for active

Table 1 Main differences between active and passive systems, and operations considerations.

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Passive/permanent may also require someone who is concerned with maintenance nitty-gritty. As much as it affects active operations, things like weather damage and animals pulling at cables can be on-going issues for non-active, and this is why it is essential to have equipment which can provide full spread monitoring whatever the terrain. There will also be various passive housekeeping duties which will not be so important to the active, for example, where solar panels are used they need to be kept clean from road dust, etc. Then there is the obvious: when using passive systems with in-field data harvesting one must consider how man-made noise can be controlled. Simple planning procedures can make a big difference. All-in-all, it is possible to use run-of-the-mill equipment and crews in a passive operation but do not expect to get the most from either. The main differences are summarized in Table 1 for easy reference.

There is no doubt that the proper use of the most modern hardware offers immensely valuable and new opportunities for those who know how to take advantage, as well as hazards for those who are not so well prepared. As Alexander Pope said: 'A little learning is a dangerous thing'; but by spending time to get better acquainted with

what is now possible the industry does not need to repeat the mistakes of the past.

Acknowledgements

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