cover page

<table>
<tr><td colspan="2">

Technical review of document:

"Natural attenuation handbook for the management of petroleum hydrocarbon contaminated groundwater"

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Contract number:

03/04 – 134S

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Review by:

Drs. Ben Keet, K8 Ltd
P.O. Box 8848, Havelock North
Ph/Fax 06 877 6059 – 021 117 1148
e-mail ben@benkeet.com

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Time table:

18 September 2003 – initial discussion with MfE staff in Wellington
14 November 2003 – report and suggested changes

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Scope:

Address the following five points and suggest any changes to the document:

1. Is scientifically correct
2. Still represents international best practice
3. Is practicable within New Zealand context
4. Is easy to understand and implement, and will result in effective outcomes
5. Is consistent with other Ministry for the Environment guidance on contaminated site management

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Summary:
The document cannot be regarded as handbook or as field guide as it does not cover all necessary elements to fully understand the position of Monitored Natural Attenuation (MNA) in the range of remedial techniques available and it lacks a practical step-by-step guide for its implementation. In its current state the document is better placed as information document for background reading and might be placed in an appendix of a report documenting an MNA application such as found in the appendices of this document.

Regarding the five review points:

1. Is scientifically incorrect as it assumes the effects of the hydrocarbons present are restricted to the plume area. It is also incomplete as it assumes groundwater to flow in one layer and in one direction, which is almost never found in practice.

2. It does not represent international best practice as it focuses only on a few of the hydrocarbons present in the contaminant mixture (common in the documents it references which date from '94 – '99). It proposes monitoring wells for long-term sampling in a biologically active zone instead of lysimeters and it does not take into account the internationally more and more required limited life of a remedial project (max. 30 yrs is commonly accepted)

3. MNA is practicable within New Zealand context, however the document is not. To be applied well in practice using only this document requires a level of expertise that is not common in New Zealand.

4. From the document it is not easy to understand how to implement MNA properly, and will effectively result in a 'do nothing' solution, which is different from MNA even though chap 2 falls short in fully explaining why.

5. The document is only partly consistent with other Ministry for the Environment guidance on contaminated site management and is inappropriately brief. Regarding the risk-based approach it does not consider combined risks of other chemicals possibly used on the site during the lifetime of the project and in its proposed application to soil contamination, free product and fresh spills. The document may lead to assume incorrectly that resource consents for discharge of contaminants to the environment will automatically be obtained in most cases. Despite being one of the first guideline documents (or information documents) to be published on remedial techniques it omits to explain where MNA fits in the broad range of in situ remediation techniques. In the description of models it does not present an easy to use comparison nor does it emphasize the importance of the right conceptual model.

Technical review of document:

"Natural attenuation handbook for the management of petroleum hydrocarbon contaminated groundwater" produced under Sustainable Management Fund project 3049.

1. General Remarks

1. The title of the document relates to processes in Groundwater, however, throughout the text it is suggested that MNA can be used for the management of soil remediation, free product and even fresh spills. While this is not untrue purely in principle, it will confuse the less experienced reader and may lead to very long MNA management projects (centuries in some cases). Furthermore in terms of risk the inclusion of these cases may confuse the average reader.

2. The title of the document suggests "a Handbook" has been prepared. Even though the document generally describes the workings of MNA it by no means can be used by less experienced staff, even with a background in groundwater or environmental management, to set-up nor control such projects, nor does it cover all aspects of MNA.

3. Throughout the text reference is made to a number of publications. Given the review intention it is confusing for the reader to find information of older papers mixed with more recent ones as the understanding of NA has evolved significantly over the last 10 years. For example figure 2 page 6 is a graphical representation showing the reduction of the maximum concentration relative to the original concentration while a parcel of contaminated groundwater moves through a porous media under different hypothetical conditions. For the inexperienced reader the relation to Figure 1 and for that matter to MNA as a whole will be very unclear without a detailed stepwise development of that concept. Figure 3 from a much older study does not add to the clarity of the subject at hand; better textbook examples are available in the literature (e.g. the protocol of Wiedemeijer published in the same year)

4. Despite reference to the effects based approach of the RMA and the Guidelines most stepwise protocols appear direct copies of the two US manuals (US EPA and ASTM) and are only found in some copied tables.

5. A major technical omission relates to the retardation coefficient, one of the principal governing parameters in assessing migrating dissolved hydrocarbons. Practically all soils contain some organic matter to which organic chemicals such as hydrocarbons will be adsorbed and desorbed leading to a slower movement compared to the groundwater itself. Suggested is several times that a slower movement of the plume compared to the groundwater flow is proof of natural attenuation, by which is suggested a reduction of contaminant concentration. This is untrue as the thousands of pump and treat projects have shown; desorption can lead to seemingly endless recovery of contaminant concentration after cessation of pumping.

6. De development of biodegradation rate constants has not halted in 1995. It is now common knowledge that the biodegradation rate is dependent on the concentration of electron donors (e.d.) and electron acceptors (e.a.) leading to 4 main groups of bioremediation rate constants:

	concentration e.d. low	concentration e.d. high
concentration e.a. low	zero order	1st order
concentration e.a. high	1st order	2nd order

2. Five Point Specific section

Discussed below are the five points as per the review contract

1. Is it scientifically correct?

The title of the document correctly suggests that MNA is applicable to hydrocarbon contamination in groundwater. However, throughout the text reference is made to contaminants in soil, free product and even to fresh spills. This is wrong and should be amended for two reasons:

1. The RMA states that discharge to soil and groundwater should be avoided and if occurred rectified. It is evident this applies to fresh spills and deletion of reference to those in the report will have to be removed. Hydrocarbons in soil at high concentrations, even present as free product, will almost certainly dissolve into groundwater and are likely to migrate themselves, which constitutes a discharge to groundwater and possibly surrounding soil. It is therefore in conflict with the RMA.

2. Eventhough NA will occur in these conditions the duration of breakdown will be very long (in some cases may be well over 100 years) and therefore ensuring monitoring over the entire project life will be difficult to control.

It is scientifically incorrect to assume the influence of the plume extents only to the area where hydrocarbons can be detected. The depletion of dissolved oxygen and nitrates from the groundwater leaving the area in which hydrocarbons are present, can have detrimental effects on the environment (trees, scrubs) in front of and along the sides of the plume, especially near surface. These effects have to be taken into account in cases where vegetation is important to the local environment.

In view of the increasing attention to emerging substances it is important to realise that most commercial hydrocarbon mixtures consist out of several hundred compounds, some of which can be more harmful and breakdown slower compared to the main components generally analysed. When sensitive receptors (water wells, discharge to standing open water, etc.) are present along the edges of the groundwater plume analysis for these compounds may be necessary to ensure safe use of thes e resources. Analyses using GC-MS with appropriate libraries for these substances *and* their breakdown intermediary products will be required for this type of monitoring.

In schematic representations of contaminants migrating with groundwater it is commonly assumed it flows only in one direction (see for example figure 4 page 13). International research has shown on many locations this to be an over simplification of the underground situation. Generally groundwater flows in different directions in different layers. The deviation from the general gradient can be slight to very significant. The deviations generally are more pronounced at shallow depth, thus in the zone of interest for MNA. Furthermore seasonal effects influence the direction of groundwater flow. These relate to areas of infiltration and evapotranspiration, which can be layed out in a very irregular pattern in urban regions. It is important to take these variations into considerations as they can strongly influence the geometry of the plume (note again: different in different layers) as well as influence migration direction and speed. A site investigation used as the basis for a MNA

remedial proposal (resource consent application) should clearly identify these topics and quantify their relevance to the monitoring strategy proposed.

Finally the document should specifically state that it only applies to non-halogenated hydrocarbons (often used in workshops / garages in the past) to avoid confusion for the less experienced user. It should also be noted that some mixtures of hydrocarbons with chlorinated hydrocarbons or PAHs may sink, rather then 'float' on the groundwater table.

2. Does the draft handbook still represent international best practice?

Internationally MNA is recognised as an appropriate remedial technique for shrinking or stable groundwater plumes. In many countries, where MNA has been practiced for up to 10 years, a finite live span of the projects has been added to the application conditions. Generally at the time of resource consent application quantified proof has to be provided that using MNA the contamination as a whole will be reduced to below remedial action levels (in Holland the eco- and human toxicological determined I-level, in the US the remedial level determined by the RBCA analysis) within 30 years. Longer projects are deemed to be uncontrollable.

In practice this means that some form of active remedial technique is applied to the hotspot(s) to remove the source(s) which feed(s) the groundwater plume(s). The resulting contaminant mass (electron donors) should be able to be biodegraded using the influx of natural existing electron acceptors being carried into the plume area by the groundwater. These consist usually out of dissolved oxygen and nitrates, however in severely reduced conditions dissolved sulphates and carbondioxyde as well as iron from the soil in which the plume is present augment these. Commonly, when application for a MNA project is made *the mass balance* of electron donors and acceptors available in the plume area (the bio-active zone) at the different stages throughout the project life (30 years) will need to be presented in the initial application request report and in the on-going monitoring reports. Attention should be given to each hydrogeological layer present (a mass balance should be presented *per layer*) as well as to possible downward migration due to infiltration of rainwater to deeper layers where the influx with electron acceptors may be more scarce and different hydrogeological conditions may apply (faster groundwater flow leading to rapid off-site migration, more dilution leading to lower concentrations, etc.)

Monitoring of the MNA project has to be undertaken in three zones: a/ throughout the plume including the source area, b/ at the front of the plume (where values of both electron acceptors and donors are just above detection limit) and c/ in front of the plume in some relevant cases including both the area where electron acceptors are affected and in front of that area. Note that the plume area is likely to be different in different layers (migration at different speeds and in different directions), which affects position of group b and c monitoring points. Not uncommon group c monitoring points in a moderately permeable layer would be the same distance from the source area as group b points in a more permeable layer at the same site, Attenuation and possible migration of the plume is established using data from all three monitoring zones. When a multi-layered soil system is present (more the rule rather then the exception) monitoring needs to be carried out in each layer. Monitoring wells screens need to be short, at least limited to the thickness of the layer of interest, commonly not more then 0,5 meter. Monitoring is preferably carried out using lysimeters (large volume porous cups sampled under N_2 or Ar gas), as bioactivity in standard monitoring wells is often *an order of*

magnitude higher then in the surrounding soil due to the open connection to the atmosphere. Therefore low concentrations are often reached in monitoring wells years before aquifer clean up. This is internationally noted as a major concern (monitoring wells are often referred to by professionals as the worst possible groundwater quality monitoring devices), however is only occasionally practiced due to existing legislation (compulsory use of monitoring wells). New Zealand should grasp the chance to introduce these improved monitoring concepts at a time of introducing new guidelines. It should be noted that the material costs of lysimeters is negligible to the placement costs (drilling) of monitoring wells and that sampling time (and thus cost) per monitoring point is greatly reduced (no purging required) as well as the chance of procedural errors occurring (limited or too fast purging of monitoring wells). Furthermore the tubes connected to lysimeters can be grouped into a few remote street access boxes, which make sampling in the middle of a busy intersection or on a highway possible in a safe manner.

Due to the bioactivity in and around monitoring wells it is common practice internationally to place fresh monitoring wells at certain time intervals throughout the project (not needed when using a 3-D grid of lysimeters). This commonly coincides with the decline of analytical values of groundwater samples from group b wells below detection limit, necessitating placement of wells closer to the source area(s) to keep within the objective of group b wells (at the front end of the plume, however, with concentrations above detection limit). Note that the decline of contaminant concentration in the group b wells is often due to the biological activity induced by the well itself and that frequently fresh monitoring wells placed at some distance from such a well, equidistant from the source area often reveals much less reduction in concentration of contaminants. As the quality of well-made lysimeters does not degrade in time these can all be placed at the start of the MNA project on a grid per layer giving 3-D coverage of the plume.

When (the) concentration(s) of contaminant(s) in group b wells has increased the monitoring frequency is increased, commonly from yearly to quarterly starting with an immediate repeat of the last monitoring event. When concentrations keep on increasing for two more monitoring events (i.e. in 3 events over a half year period) an amended remedial action plan has to be submitted (usually within 2 months) and when approved to be actioned (within 2 month after approval). Total time frame from first exceedence to implementation of an active remedial action shall not exceed 1 year. Conditions of consent usually state that when the responsible parties do not take action within the specified timeframe action may be taken by the relevant authority with full cost recovery (internal and external costs including legal).

3. Is the handbook practicable within New Zealand context

Many New Zealand soils and hydrogeological settings are similar to those found internationally where MNA projects have been permitted to start (note: no closures yet). Technically there is no reason why MNA of hydrocarbon contaminated groundwater could not be effective in New Zealand.

The 'handbook' is not practicable within New Zealand context. To be applied well in practice using only this document requires a level of expertise that is not common in New Zealand. Besides omission of important issues mentioned above and below there is no step-by-step guideline.

Discharge of contaminants to soil and groundwater is covered in the RMA and a number of regional councils and some industry groups have taken this to include migration from (historically) contaminated sites. MNA is therefore only applicable to groundwater plumes, which are proven to be stable, or shrinking in all hydrogeological layers affected by the contamination.

Adverse effects to the environment can be expected due to the reduction of natural electron acceptors like oxygen and nitrates in groundwater resulting from the biological processes in the contaminant plume area. These effects can extent well beyond the front of the contaminant plume and should be taken into account in sensitive areas. This also applies to compounds in the hydrocarbon mixtures spilled and the breakdown intermediates which breakdown slower and possibly are more harmful to the environment and/or human health.

4. Is easy to understand and implement, and will result in effective outcomes

The report lacks a simple step-by-step implementation guide for practitioners. It only shows a very general schematic monitoring well lay-out in the main text, some specialised techniques and some examples in the appendices, all of which do not fulfil some of the essential basic conditions specified above. Lacking is also specific information on field procedures, types and methods of analysis, etc. It refers to the outdated use of monitoring wells rather then the by international experts recommended use of lysimeters (especially for very long term monitoring of bio-active zones).

The report does not give clear guidance to controlling agencies as to how to control the process of resource consent application, which steps are essential, how to control the field implementation, what has to be reported and to who, the format and the frequency of reporting. A few examples of such reporting, which should be brief and tabular, would make the handbook much easier to use. The full case history reports in the appendices do not make up for the lack of this in the main text.

5. Is consistent with other Ministry for the Environment guidance on contaminated site management

The handbook has four main areas where it overlaps which existing guidance documents or will overlap with guidance documents in the future:

1. Risk based approach
2. Discharge of contaminants to the environment
3. Other (in situ) remediation techniques
4. Use of Models

ad 1. The basic premise of MNA is that risk to human health and the environment are negligible, which is in it self a poor definition and may lead to debates in each case. As the handbook specifically deals with groundwater and therefore deals only with dissolved hydrocarbons which in most cases will be present at some distance below the surface risks associated to the presence of dissolved hydrocarbons will often be low, especially when there are no dwellings within or close to the plume area and groundwater is not used and is unlikely to be used in the future.

Care should be taken however, and clearly expressed in the handbook, that co-exposure to a variety of chemicals could lead to a higher risk. This applies not only to contaminants in the hydrocarbon mixtures itself (most of which are commonly not analysed) but also to other chemicals, which may be used on the location, at present and in the future as well as the breakdown intermediates. This is important, as even minor exposure is likely to persist over many tenths of years during MNA projects. The risk assessment carried out before resource consent application should therefore take into account other contaminants or chemicals likely to be used on the site to determine the Mechanism of Action of the combination of chemicals. When this leads to an unacceptable complex risk assessment the handbook should recommend a more active form of remediation to shorten the time of exposure. When new chamicals are going to be present on the site in the future the Handbook should state that new risk assessment should be performed on the added effect of those on the Mechanism of Action of the existing mixtures.

ad 2. Discharge of contaminants to the environment needs resource consent and is covered in other MfE guidelines. Despite this coverage the handbook should make clear the boundaries in which it can be applied. Internationally MNA is not commonly practiced in actively migrating contamination thus when we keep in line with international practice MNA should be a possible remedial solution for stable or shrinking plumes consisting of hydrocarbons dissolved in groundwater. To expand the MNA principles to areas as soil contamination, free product and fresh spills is outside the scope of the handbook on hydrocarbon contaminated groundwater. *This should be made clear in the executive summary, the introduction, at the start of several relevant chapters of the handbook and at the start of appendices including the field application guides, checklists, etc. to avoid confusion.*

ad 3. Despite being one of the first guideline documents (or information documents) to be published on remedial techniques it omits to explain where MNA fits in the broad range of in situ remediation techniques. The reader is not made aware that many remedial techniques have been developed and that MNA is only one of the many approaches.

Remedial techniques are often ranked to the intensity of their action. More intense remediation means shorter project times and often higher costs. This can not directly be extrapolated to the longer the project the lower the costs: at some point on the timeline less intensive active remedial techniques may be less costly then MNA due to the mounting monitoring costs. Some techniques are only partial / temporary solutions such as isolation, which leaves contaminants on-site or treatment of specific areas usually the centre or hot spot or only the plume. Intensive treatment of only the centre or hot spot is commonly complemented with some form of extensive plume treatment, *the most extensive, but not necessary the least expensive, being MNA.* Treatment of only the plume, or segments of the plume may be applicable when the centre or hot spot is inaccessible or costs for removal are too high at this stage while down steam receptors have to be protected. The very passive techniques, like MNA, are not commonly used in these situations, as migration from hot spots is likely to be imminent or may occur when circumstances change. A brief and incomplete listing of some of the more frequently used remedial techniques is given below.

Intensive remediation techniques (often used in source / hot spot areas)

Removal of contaminants plus matrix
Excavation
Evacuation by vacuum truck
Dredging
Groundwater extraction (Pump & Treat)

Smart Pump & Treat

Free phase removal
- Removal of 'floating' layer (LNAPL)
Dual Pump Extraction (DPE)
DPE without skimmers
DPE with mechanical skimmers
DPE with oliophilic filters (Scavengers)
DPE with floating skimmers
Vacuum Enhanced Extraction (VEE)
Two phase (Dual phase) extraction (TPE, DPE)
Multi Point Recovery System (MPRS)
Bioslurping
Passive Extraction Systems
Manual removal
Passive Skimmer wells
Petro-traps

- Removal of sinkers (DNAPL)
Pump & Treat
Cusping & Coning
Fluid - fluid extraction (membrane)
Co-Solvent Extraction
Gravity Displacement
Density inversion

Mass extraction
Soil Vapor Extraction (SVE)
Airsparging + SVE
Electro reclamation (electro-osmosis, electrophoresis)
In-situ in well stripping (with or without UVB™ wells)
Ultrasonic

Intensive chemical treatment
Oxidation
Ozone (for example in C-sparge™)
Advanced Oxidation Techniques (AOT): for example Peroxide, Permanganate
Fenton's reactions
Oxygen injection
Dissolution with acids
Complex-ion flushing
Surfactant flushing
Co-solvent flushing

Intensive biological conversions
Bioventing
Bioslurping
Biosparging
Alternative electron dosing (AED) under reducing conditions
Biochemical conversions (cyanides)

Augmenting processes
Surfactants / detergents
Soil heating: Hot Air, Electrical (AC, DC en 6 phase), Electromagnetic (EM), Radio frequency (RF),
In-situ Thermal Decay (ISTD)

Steam stripping
Steam + chemical oxidation (thermally enhanced oxidation)
Circular flow processes (C-sparge™, UVB™, GHCD™)
Acoustic
Soil mixing (for example by drilling very large diameter boreholes close together while mixing chemicals into the soil)

Immobilization processes

Solidification
Cement injection
Lime injection
Vitrification (includes burning organics)

Immobilization
Precipitation
Detergents to encapsulate organic contaminants
Gelling

Isolation

Capping
Physical capping
Biological capping (cover with plants which produce higher evapotranspiration then the annual precipitation)

Containment
Vertical barrier walls
Sheet piling steel
HDPE walls en HDPE Sheet piling
Hydrological control
Biological control (bio-active zones)
Cement Walls (vertical)
Bentonite, Bentonite –cement of Bentonite – fly ash walls
Horizontal barrier walls
Cement sheets (horizontal) (other materials: waterglas, epoxy, bentonite)
Liners (HDPE, Bentonite impregnated, etc.)

Remediation of plume zones

Techniques for total plume remediation
Unsaturated zone
Phyto remediation
Bioventing
Soil heating with earth heat (isolation)
Saturated zone
Biosparging / In-situ aeration
Micro-sparging
Diffusionspargen ™
Alternative electron acceptor dosing
Monitored Natural Attenuation (MNA)
Substrate dosing: fluids
Substrate sparging: injection of gasses
Concentric u/g re-circulation processes
Precipitation: Irreversible reactions

Techniques for discrete zone treatment (often in plume area)
Physical and chemical zones
Hydrological recirculation wall
Permeable Reactive Walls (PRB): for example
Biological walls
Bio-fence
Sand wall
GHCD – membrane system fence for shallow or deep groundwater
GHCD ™: nitrate remediation in deep groundwater
Substrate wall
Carbon wall
Micro-sparge fences
Oxygen Release Compounds (for example ORC™) fence
Hydrogen Release Compounds (expl. HRC™) fence
De-chlorinator fences
O2M-fence: Diffusion sparging
Electro O2M fence
Chemical walls
Zero-valence walls
Iron wall
Electro kinetic fences
MNA

Funnel & Gate
F&G with groundwater extraction
F&G without groundwater extraction

Trench & Gate
T&G with bio-assistance

Many promising new techniques are being tested, such as direct dechlorination of VOCL's using titanium activated vitamin B12 (some vitamins to make the soil healthy), direct injection of special bacterial cultures (something like soil antibiotics), etc. of which one day hopefully will be derived new efficient and economic alternatives for even more complex situations.

4. The main omission in the section about the use of models is the warning that without the right conceptual model of the subsurface conditions no analytical or numerical model outcome will represent reality. In the description of models lacks a listing of basic assumptions about the processes made (in some models these are quite unrealistic) and the non-tabular form does not allow for an easy comparison.

Models should be used to provide the investigator more insight, or to assist with fine-tuning a sampling strategy. Without calibration or history matching *no model should ever be used* for predictions. Unfortunately easy (and often erroneous) models are often used to create good-looking graphics to impress the customer as well as the public.

Easy to use models may be just one-dimensional 'streamline' chemical or biological conversion models running on spreadsheets with or without the flash graphical outputs. This is the type most used by experienced staff, as they are quick and simple, however offer greater insight in the dynamics of the hydrochemistry in a bio-active groundwater system. However

fully integrated biochemical-hydrogeological models remain the ultimate aim of the real fan of models.

Care should be taken with the many low cost and easy to use public domain or commercial models on the market. Like programs to analyse pumping tests in hydrogeology they only provide correct outputs when the input data are correct *and all assumptions on which the model is based fit the situation at hand*. Unfortunately this is *very seldom* the case. For general use two analytical programs both running in spreadsheet format are available free of charge. For completeness the chlorinated models are included in the list, to highlight the fact that they are to be used for chlorinated compounds only, even though some numerical versions have a non-chlorinated option.

Bioscreen   Assumes the breakdown speed of dissolved phase is similar to that of adsorbed phase.
(for BTEX)   This is of course very untrue. When organic matter in soil is > 2% this creates very large
               mistakes. The use is simple, however when plotting values errors are easy made.

Biochlor   Errors in assumptions: Retardation coefficient is the same for all VOCL's. 2nd mistake is
(for VOCL)   the assumption that the adsorbed phase will hardly degrade (no exchange). The model
               assumes only 1 breakdown route (Per-Tri-Cis-VC-etheen). The model use is simple.

Numerical Model	- Number of contaminants + Type of reaction simulation	- Sorption - Source treatment	- **Ease of use** - **Dimension of dispersion** - **Choice for use**
BioTracker	- Unlimited + Breakdown in order + Option for Cl^- accumulation	- Linear isotherm – equilibrium sorption - R = contaminant dependent - Option to select breakdown of sorbed contaminant to zero - Assumes constant source (weak point)	- Average - 1-D - 1-ste for VOCL
MT3D	- One + Only 1st order breakdown	- Many isotherms – equilibrium sorption - Breakdown rate differs in dissolved and adsorbed phase - Assumes constant source (weak point)	- Easy with pre-processor - 3-D
MT3DMS	- Unlimited + 1st order breakdown (not coupled)	- Many isotherms – equilibrium sorption - Breakdown rate differs in dissolved and adsorbed phase - Assumes constant source (weak point) or limited dissolution of 1 component	- Easy with pre-processor - 3-D - 1-ste choice BTEX
MT3D99	- Unlimited + Assumes instant electron-acceptor reactions (not realistic)	- Many isotherms – equilibrium sorption - Breakdown rate differs in dissolved and adsorbed phase - Assumes constant source (weak point) or limited dissolution of 1 component	- Easy with pre-processor - 3-D
RT3D	- Chlorinated ethenes, ethene and chloride OR - Total BTEX, O_2, NO_3, Fe(II), SO_4 + Breakdown order fixed (with Cl balance for VOCL's) + 1st order BTEX with simultaneous electron acceptor reactions (with limiting constants (not realistic)	- Assumes breakdown of sorbed phase can be neglected (not realistic in source area) - Assumes constant source	- Easy with pre-processor - 3-D - 2-de choice for VOCL (plume areas)
Bioplume III	- Total BTEX, O_2, NO_3, Fe(II), SO_4, CH_4 + 1st order BTEX breakdown with mass coupling to dominant electron acceptor	- Unclear how breakdown of sorbed contaminants is treated - Constant source	- Difficult due to poor pre-processor - 2-D
BioRedox-MT3DMS	- Several + Breakdown order fixed (with Cl balance for VOCL's) + 1st order oxidation coupled to the dominant electron acceptor reactions.	- As MT3DMS only now with equilibrium sorption - Options: Constant source, or reducing source (e.g. Landfill), or more-component NAPL solution with choice out of equilibrium or dissolution speed limited	- Very hard (no pre-processor available in 2001) - 3-D

Postscript

Soil and groundwater contamination are intricately connected and in general terms are both present everywhere in the ragged 3-D envelope denoting the outer shell of the contaminated area. The concentration of dissolved contamination; adsorbed contamination and contaminant vapours are related to each other through the different partitioning coefficients. Remedial focus on only the dissolved phase (groundwater) is impossible as this phase is in constant equilibrium with the other phases. The adsorbed phase holds commonly the largest mass of hydrocarbons in a soil – groundwater matrix when no free product is present. If free product is present it acts as a reservoir to keep concentrations in the other phases near saturation. Even in sandy soils low in organic matter (1%) often well over 100 times more HC mass is adsorbed on older (10 year+) contaminated sites. On many sites this factor may even be well over 1000 (note this is far greater then the theoretical amount due to aging effects of the product and deep penetration on soil particles). This means that:

1. The mass of contaminants present outside the area with measurable soil contamination is significantly larger then when determined only from the concentrations resulting from groundwater analysis. Commonly only a few components of the hydrocarbon mixture are analysed thereby exacerbating the mass discrepancies when carrying out mass balance calculations.

2. Even in the near front end of the groundwater plume more soil then groundwater contamination is present, as adsorbed phase is far greater then the dissolved phase mass, even though the concentration of soil contamination may be below detection limits.

3. In the centre of the contaminated area the dissolved phase concentration is limited by the solubility coefficient of the individual hydrocarbon components, which are considerably lower in the presence of many other components (all competing for space in the solution).

4. When outside the area where free product is demonstrated groundwater concentrations of individual hydrocarbons are present close to their solvability coefficient free product is likely to be still present as small droplets. For example the solvability coefficient of benzene is approx. 1780 mg/ltr, however as part of a petrol mixture dissolved in water this drops to 30 – 40 mg/ltr. Concentrations over this value means free product droplets are present and have been sampled with the groundwater. Note that in the laboratory these samples often need dilution to obtain the correct concentration, as the GC is set-up to produce correct results in the lower range (1000 – 100.000 times lower then saturation). So the investigator should take note that a reported concentration of approx. 20.000 µg/ltr could indicate that the detector was saturated, but no dilution was carried out to obtain the exact value.

General Comment

Clearly MNA implementation and monitoring is not as easy as it seems. Therefore it is recommended to centralise the approval process initially, by having the MfE providing a second opinion to letters of reply to MNA applications made by regional councils for the duration of 2 years. This period may need extending for councils with limited resources or where too few MNA applications were made to build the required in-house experience. A yearly mini-symposium hosted by the MfE for regional council staff ensures assessment of all applications will remain on similar or at least parallel tracks.

Page by page review

pag 1; 3rd paragraph; line 3:

the handbook on MNA in Groundwater is not applicable to recent release sites, as most hydrocarbons are not yet dissolved in groundwater

pag 1; 3rd paragraph; line 5:

insert groundwater between residual and contamination

pag 3; last paragraph:

why call it 'Handbook'? In its current form it neither is a guideline, so 'information document' may be more appropriate.

pag 4; title:

Title question not answered in chapter

pag 4; 2nd paragraph; line 4: add underlined section

……assessed and be minimal/non existent

pag 4; 2nd paragraph; line 4:

leave out: or that conditions are right for natural attenuation to occur

pag 4; last paragraph:

Note that the documents title's reference to groundwater not repeated here. The text of this chapter implies MNA is equally applicable to soil contamination. As the mass of soil contamination is commonly several orders of magnitude larger and the bioavailability often very much lower the application of MNA to 'any' HC-soil contamination case oversimplifies the real life situation and will lead inexperienced users astray.

pag 5; 1st paragraph; line 2:

Statement too simplistic
MNA processes do not always reduce toxicity, in some cases the by-products are more toxic
MNA processes in HC plumes very often *increase* mobility
MNA processes in HC plumes very often *increase* bio-availability

pag 5; 1st paragraph; line 13

Misunderstanding of the subsurface system: exchange of contaminants between soil particles – groundwater is an equilibrium process and if concentration in groundwater drops the contaminants will be desorbed from the soil particles to reach equilibrium again. Often well over 100 times more mass is adsorbed, meaning when all groundwater in a volume of soil would be replaced by a similar volume having a contaminant level of zero, the equilibrium

process would bring the concentration in groundwater back up to nearly the same level as before (approx. 99/100th) and this lowers the concentration in the soil to 99% of initial. The soil system has therefore a large buffering role, resisting change in concentration in groundwater.

pag 5; last paragraph

omitted is that most by-products of biodegradation are other hydrocarbons and organic acids, only the very final by-products are carbon dioxide, ferric iron and methane gas

pag 6; in figure

The term Dissolved Hydrocarbons in the unsaturated zone is misleading

pag 6; figure 1: Notes

delete 'volatilised or sorbed' microorganisms live in water and degrade therefore only dissolved hydrocarbons: to degrade volatilised or sorbed contaminants these first have to be dissolved.

pag 6; paragraph 2; line 4:

Add L to NAPL - ......thus Light Non- aqueous...

pag 6; paragraph 3; line 3:

RNA-needs to be explained

pag 6; paragraph 4; line all:

There are two patterns....... (whole sentence)- Note figure 2 is **not about** aerobic/anaerobic biodegradation: did authors understand the figure?

pag 7; figure 3:

Figure is not very expressive and should not be used in a base-text. Better to use a more classical or textbook example, or use a hypothetical graph.

pag 7; paragraph 3:

very short and for inexperience reader this paragraph is just as complex to understand as the table below

pag 7; table 1:

confusing to inexperienced reader who possibly does not understand the meaning of Terminal Accepting Process (misses word Electron after Terminal)
Table should be altered significantly (order of components [here mysteriously called determinant], grouping in electron donors & acceptors)

pag 8; paragraph 1:

5 times management in 5 sentences

pag 8; paragraph 2; line 2:

… in-situ ….. – not explained (generally written without the -

pag 8; paragraph 2; line 3:

potential for cross media transfer of contaminants – too difficult for intended readers

pag 8; paragraph 2; line 5:

to or of?

pag 8; paragraph 2; point 4:

this MNA handbook is about groundwater

pag 8; paragraph 3; point 5:

move it to the top as it is most important

pag 8; paragraph 3; point 1:

"may be" change to: are very likely

pag 8; paragraph 3; point 2:

could = is certainly

pag 8; paragraph 3; point 5:

……less than **poorly** engineered

pag 10; paragraph 1; line1:

Remark: do not mix concepts of risk and remediation; if risk NO MNA

pag 10; paragraph 1; point 1; line 6:

leave out…and the plume will be shrinking – makes no sense: organic contaminants ALWAYS move slower than groundwater in natural soil systems; statement is misleading

pag 10; paragraph 1; point 1; line 9:

mass loading rate = dissolution (too complex wording)

pag 10; paragraph 1; point 2; line 7:

……are often indicative……(insert often)

pag 10; paragraph 1; point 2; line 10:

replace: temporal and/or spatios trends of contaminants - by- reduction of electron acceptors

pag 10; paragraph 1;point 2; line 11:

… stability ??? what is plume stability?? concept not explained before

pag 10; paragraph 1; point 3; line 2:

cannot be done in lab: Dr. Wilson (US EPA) said once: 'lab microcosm studies are worst than a sick baby', and in field are very difficult.

pag 10; paragraph 1; point 3; line 5:

contaminants…… are models part of Tertiary Lines of Evidence or do they apply to whole group: if so why in 3rd point

pag 10: general: the 3 lines of evidence system is dated. Missing are inclusion of dynamics of system, multi-layered approach, heterogeneity of processes (anaerobic breakdown inside silt lenses embedded in aerobic sandy aquifer). Also missing the VERY important concept of mass balances and last but not least that breakdown rates are concentration dependent leading to 0, 1st or 2nd order of breakdown rates

pag 11; paragraph 1+2:

too formal for NZ 'handbook'; is typical US nomenclature

pag 11; paragraph 3; line 1:

much of the data ………………nonsense: in standard site assessments only the contaminants are analysed. Missing are most or all electron acceptors, all intermediates, and the time-evolution of concentration. Furthermore most site assessments of HC contaminated sites do not take into account multiple layers or seasonal changes in groundwater flow direction. In short standard ESA's hardly contain data for MNA evaluation.

pag 11; paragraph 3; line 3:

……may –must be replaced by- is always needed

pag 11; paragraph 3; line 5:

Table 2 = not complete, not practical to use, does not give standards on sampling / analysis, etc.

pag 11; section 5.3

generally far too simple; guidelines given apply to a hypothetical site with only 1 layer of homogeneous soil; practically everywhere is missing: For each layer……….., or …….per layer.

pag 11; point 4 of 5.3

monitoring screens should not 'just' be all the same length: they should match the thickness of layer of interest, generally being at least 0.3 m shorter on either end of the layer allowing bentonite plugs above and below. Common screen lengths for MNA projects s 0.5 m.

pag 12; point 2:

and seasonal / annual changes in direction of flow in each layer.

pag 12:

missing: -   several mon. filter depths if soil is layered
        -   3D flow characterisation (thorough hydrogeological conceptual model of site (in situ groundwater flow [3-D direction and velocity] meters are available from several suppliers)

page 12; general: Monitoring Wells are in principle NOT suited to monitor effects of biological breakdown as they INFLUENCE the measurement due to connection to atmosphere. The only correct sampling devices are lysimeters.

pag 13; figure 4:

At least add side wells to obtain insight in lateral movement groundwater direction; also lacking is standard grouping of wells into a/ monitoring points in contaminant zone to determine reduction of concentrations, b/ monitoring points at the front of the plume, however where concentrations are above detection limits and c/ monitoring points in front of the plume to be used as alarm points in case unexpected migration does occur.

pag 13; table 2:

Very unpractical, especially for inexperienced users.
Specifics:
data of release is generally unknown, and often comprises several or continuous releases
historic concentrations are often not known
delineation of sources should include masses released (contaminant) and masses available (influx of electron acceptors)
table omits to indicate that many concentrations are needed in and outside the plume
mass balance is lacking
live-span electron acceptor availability is missing
no reference to use of isotopes
generally table is taken from a too old publication to be up to date

pag 14; paragraph 1:

RNA (unexplained) or MNA? What are we talking about?

pag 14; paragraph 1; point 2; line 5:

how do you know when this condition is reached? no reference to possible risks in source area during all the time needed to reach this situation

pag 14; paragraph 1; point 3; line 3:

Point 3 should be point 1

line 3 attenuation – no reference given to co-contaminants present: Underlying assumption that TPH BTEX are sole contaminants of interest is antiquated and incorrect.

pag 14; paragraph 2; line 4:

to be added to e.g. leaking UST *[give in full]* removed should be and free product and highly contaminated soil removed: when such a source is left in the ground the MNA project will last decennia. It is also irresponsible to leave free product / severely contaminated soil in place when excavating a tank, as the effort to do so is minimal and the possible (likely) effects to the environment (migration) are significant.

pag 15; paragraph 1; line 1:

Two concepts are mixed which is confusing: reduction of high concentrated source area due to flushing (i.e. dilution) and dilution of concentrations in plume area, which will cause lowering below action level. What lacks is that due to the first process the concentration in the plume area will rise first. In principle this is not allowable under the RMA.

pag 15; paragraph 2; line 2:

duration : add (minimum of 5 years, or longer if local situation is likely to change) reference to multi-layered system should also be added.

pag 15; paragraph 3; general

MNA should not be applied to expanding plumes (this is in principle an uncontrolled discharge)

pag 15; paragraph 4; before line 1:

add: HC plume's always expand at lower rate then groundwater flow as retardation is always larger then 1, to reference to the lower rate of expansion is misleading to inexperienced user.

pag 16; 6.3 general

Source removal and free product are not elements of MNA: they should not be discussed in this document, but referral be given to other documents dealing with active remediation.

pag 16; paragraph 1; line 3:

Section uses too difficult / theoretical wordings such as 'mass loading rate'

pag 16; paragraph 1; end:

Reference to supplementary monitoring wells in relation to reducing risk is misleading, as monitoring wells do not reduce risk

pag 17: 6.4

In general document for practical application this section would be better placed in an appendix

Main omission leading to MAYOR mistakes is absence of retardation coefficient. All formula's given are for conservative (generally anorganic) contaminants such as salt.

pag 17: last paragraph

Very MISLEADING due to omission of retardation coef. Dissolved HC plumes ALWAYS move slower than groundwater.

pag 18; paragraph 1; line 3:

'banded TPH' - what is this?
……line – what line?

pag 18; paragraph 1; line 5:

one year – too short given MNA speed ; generally monitoring is done at t=0, t=3 months to check t=0 data, then t=1 year, if change do t=2 year and stay on every 2 years till concentration is halved / plume size reduced significantly or when no sign. change do t= 3 years and then every 3 years till concentrations are halved / plume size reduced significantly, then every 5 years till below background levels.

pag 18; paragraph 1; line 7/8:

1- note that breakdown rate is concentration (donor and acceptor) dependent and occurs in 0, 1st and 2nd order. Unfortunately in practice these processes may all occur in the same soil volume, on different or same contaminants. Processes as dilution and uptake by vegetation are 0 order processes that are superimposed on the total giving rise to significant deviation from this theoretical ln C versus t line.

2- in percent per day – really? show in formula

pag 18; last line on page:

change …… does not always signify…. to ……has nothing to do with ………

pag 19; figure 7:

Only applicable when simple 1st order breakdown is assumed; not commonly seen in practice.

pag 19 lower half

While statistical approach increases objectiveness of conclusions with MNA studies a large portion of the subjectivity is introduced in the way the samples are taken and by the choice of position and type of monitoring devises used.

pag 20; paragraph 3; line 1:

'it is not the function of this Handbook…' – so what is the function of a 'handbook'? To be a handbook it should include ALL relevant data, procedures and method, to be a guideline it should be practical to apply, not only give reference to documents generally not on the bookshelf of inexperienced users.

pag 20; last paragraph

So we mix 0, 1st and 2nd order processes and simplify to 1st order and hope to be precise enough to apply complex statistics or determine biodegradation rate constants (which then include advection, dispersion, sorption, dilution, volatilisation AND biodegradation). Given this approximate nature is it really essential to devote the whole of page 21 on formulas? Or is this just to make MNA look 'accurate' and 'calculable' to the inexperienced user?

pag 21: all equations

Missing again is retardation coefficient
Missing as well is that each layer requires it's own calculation
Mass balance (e.a. vs. e.d.) missing

pag 22: line 2

Use of conservative tracer (trimethylbenzenes) is a relevant method and would deserve more text space (over the equations). However the method is dated and superseded by the stable isotope method.

pag 22; paragraph 3; line last:

after mg/l, (add) and dissolved oxygen (DO) in the plume is a lot lower, then……

pag 22; paragraph 4; line last:

(add at end)…………. or has taken place.

pag 22; last paragraph; line 8-12:

real soil isn't homogeneous and isotropic conditions, which applied quite well to the BTEX plume in the gravel aquifer at the Hill AFB on which the first MNA protocol was based and which is referenced in that 1996 US EPA report. In practical ALL other cases investigated

after that case study it appeared that the electron acceptors all NOT consumed one at a time but rather all simultaneously. The so-called separate NA zones given in the initial protocol appeared in other case studies to be very mixed. methanogenic processes (for example inside the free product zone) occurred at less then a meter from aerobic breakdown.

It should be kept in mind, and made very clear to the reader that these theoretical cases are exception rather then rule.

pag 23; paragraph 1; line 1

assuming this sentence refers to the last paragraph: Fe (lll) is not a tracer!!

pag 23; paragraph 1; all 3 points:

These are not tracers.

PH is not a good indicator, many soil systems are strongly buffered (again the Hill AFB gravel aquifer was not). The increase of calciumbicarbonate concentration can be used as indicator of aerobic breakdown (result of buffering of CO_2).

pag 24; paragraph 3; line 1

isopleth (contour line of equal concentration) seems overly scientific in the context of this document.

pag 24; paragraph 3; line 5-7:

apart from being a very difficult way expressing a simple process again the general concept of mass balance is left out

pag 24; paragraph 4; line last:

intrinsic bioremediation – mentioned for the first time: what is intrinsic vs. natural?

pag 25 figure 9

Figure is theoretically correct, however in natural multi layered systems the well defined reduction and increase of these components will generally not be easy to demonstrate: This should be made very clear.

At the time of writing (1984) few practical examples existed. Now we know that not every source area is methanogenic and that the aerobic zone from upstream usually encroaches into the source as well. Due to the multi-layered-ness often DO > 0 is measured even in the source area. When this is not explained in such a basic 'handbook' the inexperienced used will be put off guard the first time he reads such values in reports / measures them in the field.

pag 25; paragraph 2; line 6:

…….. worst case – replace by…… realistic

The contaminants' industry pre-occupation with worst-case scenarios has lead very often to no action, as the costs based on a worst-case scenario are often exorbitant. After 20 years of contaminated site management experience a fresh 'Handbook' should not lead the inexperienced user on a path which has been proven to lead to 'do nothing' in the past.

pag 26

See comments on models in main text. Generally of all models given the basic assumptions / conditions of use are not given. An inexperienced user may conclude that each model can be applied to each case and that he/she only has to chose between screening, 1, 2 or 3 D modelling etc.

Most models, when used correctly, are only to guide an investigation (pin point areas of uncertainty) and may be used to evaluate different remedial scenarios. In terms of depicting a realistic picture of future plume development most models either fail or will cost a lot (often considered too much) to collect all required data and carry out extensive calibration / history matching.

pag 27:

a simple pro's and con's table for the models discussed would be useful.

pag 28 title

It is odd to see that only now, 5 pages before the end, the MfE Handbook to be is dealing with NA in New Zealand

pag 28; paragraph 2;

Lines of Evidence: too US based
Sentence in line 3 ………has been……….. is not complete

In general the simplification given in the 3 points should not be made.

The certain situations need further clarification.

Whole paragraph is far to short and does not do justice to the more in-depth approach given earlier. Perhaps time ran out, however a stepwise guideline would be suited at this point in the 'Handbook'

pag 28; chap 7.3 1st paragraph

Clearly the sentence as well as the whole 'Handbook' is about groundwater. Source control therefore is not only the repair of some hardware but also primarily control (i.e. removal or active remediation) of the source area. Thus removal of serious soil contamination and all free product as this will keep feeding the contaminants to groundwater, the recourse we like to protect.

pag 28; paragraph 4; line 2+3:

……then it may be acceptable to leave free product in place (MfE 1999). – In terms of a MNA the objective is not 'to do nothing' but to obtain maximum assistance from natural processes in the contaminant removal in a sustainable way. When the source area keeps feeding contaminants to a groundwater plume, not only will this process keep using natural resources (electron acceptors) which are then no longer available for other natural processes for which they were intended, but also do we stretch the duration of the project to such long times that they become unmanageable.

It should be noted that in most cases recovery of free product is practical and usually not accompanied by such risks that is is unacceptable.

pag 29; paragraph 2; line 2:

Wilful discharge of contaminants occurs when contaminants are knowingly left in the soil at such concentrations that they will spread. When there is a difference in concentration in the contaminated area general diffusion will equalise the concentration and thus migration and therefore discharge of contaminants is a logical result of leaving contaminants in the ground. Expanding plumes are therefore not to be treated using only MNA; MNA can however be of assistance. At the start of the decontamination project however the source (meaning most free product and heavy contaminated soil, have to be removed to ensure stable or shrinking conditions. In case expansion is found to occur, immediate action has to be taken in the form of further source removal or active plume treatment / interception.

pag 29; paragraph 3:

By the time an expanding plume may have reached stable conditions it may have contaminated a significant area, likely including neighbouring properties. Surely this cannot be intended by the RMA and should not be expressed in this manner in a MfE 'Handbook'. The fact that it may require more paperwork will not deter the owner of contamination following the route toward obtaining acceptance for expanding plumes. Expansion of plumes should therefore be excluded from being treated by MNA a priori, however when a plume has been proven to be stable in all layers concerned a small expansion due to an unexpected or exceptional seasonal effect can be catered for by a well designed monitoring and action plan.

pag 29; chap 7.4:

The use of primary / secondary etc Lines of Evidence in inappropriate for a non-litigation based society such as New Zealand. Emphasis should be on the pragmatic implementation of MNA. To obtain thorough data may take time, time which should be spend well by collecting the right data from the start in a sufficiently quality manner that it can be used later. A general ESA procedure is not a good starting point for a MNA site assessment. Specific investigation protocols have to be followed, when statistically significant data trends are required by time of application of resource consent.

Again the mass balance, both passive as well as active, are lacking. These are now considered primary tools to evaluate MNA.
Intrinsic tracers, stable isotope data are other, more up to date, indicators of natural attenuation occurring.

Finally in many cases the cost of very long term monitoring can be greatly reduced by application of an extensive remedial technique. The simple planting of trees may be sufficient

to decrease the plume life by 50%, or convert an expanding plume to a stable plume. A 'handbook' on natural attenuation should provide insight to the wide range of options, which have been developed to utilise natural means to cope with contamination

pag 30; paragraph 1; line 7+8:

if data are inconclusive a model will be useless: leave sentence out or totally rewrite.

pag 30; paragraph 3

A monitoring plan is an action plan, not a historical overview. To keep it readable it is best to stick to clear instructions, what to be do, how to do it, when to do and to report it. It should include a cascade of actions in case values found are outside the range predicted / expected (hoped for). It should highlight which actions the regulating authorities will take when the time schedule is not adhered to.
It should emphasise not to use monitoring wells, but recommend lysimeters.
The time-steps should be small enough in the start of the project to notice any expansion of the plume, and large enough once stable / contracting plume conditions have been proven that results are significant given the variability in analytical results. Thus when the accuracy of an analysis is 20 % timing a monitoring program to measure 5 % reduction is not cost-effective.
Triggering of action plans should occur on evaluation of all 3 groups of monitoring wells:
a/ monitoring points in contaminant zone to determine reduction of concentrations,
b/ monitoring points at the front of the plume, however where concentrations are above detection limits and
c/ monitoring points in front of the plume to be used as alarm points in case unexpected migration does occur.
As this will provide a better insight and may defer expenditure. For example due to mineralisation of humus often contaminant levels are higher in springtime (release of bound residue) in exceptional sudden or warm springs this may cause trigger levels to be reached.
The same hold for masked expansion in autumn, when concentration of total field could indicate migration but individual wells near the toe of the plume may not (yet) have reached trigger levels.
MNA projects end when contaminants are below levels of concern, which mean background levels or the level, which would normally trigger a further site investigation. The reason is simply that when an MNA project is closed, the site is crossed of the contaminated site register. Consequently when the site is then sold and ESA should not find significant concentrations of contaminants.

As throughout the MNA project contaminants will be discharged from the source area resource consent will generally be required.

pag 31

The groundwater monitoring requirement at current level of best available practice are significantly different from the requirement given (it is unclear to which 'Guidelines' is referred to in line 2).

point 1: monitoring wells are not appropriate for monitoring groundwater quality in bioactive zones.

point 2: monitoring NA should not be undertaken in wells straddling the groundwater table, as continuous aeration of groundwater in the well will be the result

point 3: placement of monitoring points should take into account the different layers encountered (a thin gravely layer of 0.1 m has a larger influence on migration then a thick (few meters) clay layer. Placement should also take into account the seasonal and annual fluctuations of groundwater flow direction. This generally results in monitoring at 3 or more levels at positions laterally covering the area of the plume at the three positions mentioned earlier: a/ monitoring points in contaminant zone to determine reduction of concentrations, b/ monitoring points at the front of the plume, however where concentrations are above detection limits and c/ monitoring points in front of the plume to be used as alarm points in case unexpected migration does occur

point 4: data on the inflow of electron acceptors is useful to make the mass balance required to determine whether breakdown will be faster then migration and to determine how long the MNA project will take to have reduced the contaminants to the required levels.

point 5: in case sensitive receptors are near the contaminated area care shall be taken to monitor specifically the high permeable layers in which migration is expected to take preference.

point 6: variations in groundwater flow need to be assessed, initially per season, to understand the hydrogeological system on site. In a multi-layered system the use of in situ flow meters is recommended. When diurnal variations are expected to be significant the use of data loggers is recommended.

pag 31 chap 7.8

Monitoring frequency is dependent on the expected migration speed. The frequency of MNA monitoring in a homogeneous heavy a soil contaminated with heavy fuel oil will be very different from that on a site with many course sand and gravel layers contaminated with aviation gasoline. In the first case MNA monitoring events may take place at t=0, 1, 10, 20 years etc. while in the second example t= 1, 2, 3, 6, 9, 12, etc. months may be more appropriate. While in the first case it may be prudent to place several deep monitoring points, to monitor whether or not the contaminant or its (more mobile) intermediaries leak through in an underlying more permeable layer, this is not essential in case 2 as the most permeable layers are the ones we consider and are sampling already.

Therefore a very site-specific approach is required.

Appendices

In a well written handbook or step-by-step field guide full reports, as case studies have no place. If so desired, reference can be made to the reports. The reports only serve a purpose when their highlight a certain ridged format which has to be adhered to by other practitioners. The reports attached do not have such a format.

Furthermore the reports describe practices, which are in line with the current version of the 'handbook' and therefore may give a wrong message after the edits above have been incorporated.