# APPENDIX A

# CALCULATIONS

JOB NO.: 11176662

MADE BY: C. Pawlewski DATE: January 30, 2013

CHECKED BY: A. Monti DATE: January 31, 2013

PROJECT: West Side FS

SUBJECT: Oxidant Demand Calculations

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1. **Background and Purpose**

This calculation has been prepared to estimate the quantity of oxidant (sodium permanganate) necessary to effectively treat the remaining PCE contaminant mass present in an area downgradient of the site source area.

2. **Design Criteria**

Design criteria used for calculating the amount of oxidant (sodium permanganate) required for remediation are discussed below.

**a. Area of Remediation**

The remediation is based on targeting four zones within the groundwater plume with PCE contamination. The area of each zone is defined by the number of injection wells and the assumed radius of influence for each injection well (i.e., 30 feet). The dimensions and estimated areas for each zone are presented below.

| Zone | Width (ft) | Length (ft) | Area ($ft^2$) |
|---|---|---|---|
| Shallow | 3,600 | 60 | 216,000 |
| Intermediate > 100PPB | 6,000 | 60 | 360,000 |
| Intermediate > 1000PPB | 1,440 | 60 | 86,400 |
| Deep | 2,160 | 60 | 129,600 |

**b. Saturated Thickness**

The estimated saturated thickness for each zone is presented below.

| Zone | Saturated Thickness (ft) |
|---|---|
| Shallow | 20 |
| Intermediate 1 | 30 |
| Intermediate 2 | 30 |
| Deep | 30 |

**c. Soil Porosity**

A porosity of 30% is used for the calculation based on the plume investigation report prepared by Malcolm Pirnie. Inc. (Malcolm Pirnie, 2009).

**d. Contaminant Groundwater Concentrations**

Recent groundwater data was used to estimate PCE concentrations in the groundwater plumes as summarized below.

| Zone | Estimated Average PCE Concentration (µg/L) |
|---|---|
| Shallow | 75 |
| Intermediate > 100PPB | 400 |
| Intermediate > 1000PPB | 2,000 |
| Deep | 200 |

**e. Permanganate Natural Oxidant Demand (PNOD)**

The PNOD is a measure of the oxidant demand of the soil regardless of contamination, i.e., the oxidant demand occurring naturally. It is also referred to as permanganate soil oxidant demand or PSOD. The PNOD is usually determined by analyzing one or more samples collected from the aquifer material for this parameter. Samples were not collected from this site; however, a value of 1 $gKMnO_4/kg$ soil was used for the calculation of oxidant demand. This value was successfully used as the value for the OSER Ave. and Kliegman Brothers sites located in the same vicinity as this site, and will also be used for this calculation.

**f. Effective PNOD**

Based on Carus Corporation's experience in the field, they have developed the concept of effective PNOD. They have determined that laboratory results for PNOD are not reflective of permanganate demand in the field,

i.e., oxidant demand in the field is less than predicted by laboratory results. The discrepancy is due mainly to the following: 1.) laboratory results are based on well mixed soil that does not occur in the field when the oxidant is injected; and 2.) permanganate does not usually persist long enough in the field to oxidize all the PNOD present. The effective PNOD can vary; however, based on Carus' experience the effective PNOD is typically 10% of the measured PNOD. A value of 10% is used in this calculation

**g. Average Stoichiometric Demand**

Different compounds require different amounts of permanganate for oxidation that is based on stoichiometry. The stoichiometric relationships for the chlorinated alkenes are presented in Principles and Practices of In Situ Oxidation Using Permanganate by Siegrist, et al. These stoichiometric relationships are included in Attachment A. For PCE, the stoichiometric demand is 0.96 lb $MnO_4^-$/lb contaminant.

**h. Confidence Factor**

The confidence factor is a safety factor applied to the estimate based on the availability of data for the site and the unknowns and variables associated with the remediation. The confidence factor generally ranges from 1 (very confident) to 5 (not confident because data is minimal or site geology is highly variable). For this site, there is some subsurface characterization data available for the target remediation area, and the geology is somewhat variable but reasonably well known. However, the PNOD was not determined by analyzing samples from the site, reducing certainty in the calculation. In addition, the remediation will occur in a residential area, so it will be desirable to minimize the number of injections to minimize disturbance in the residential neighborhood. Therefore, it seems prudent to use a conservative confidence factor to reduce the probability of needing more injections after the calculated quantity is injected. On this basis, a confidence factor of 5 was used for the calculation of total oxidant demand.

## 3. Oxidant Required for Remediation

The oxidant required for remediation was calculated using the Carus spreadsheet with the input parameters discussed in Section 2 above. These calculations are included Attachment C. Attachment C includes calculations for RemOx S (potassium permanganate) and RemOx L (sodium permanganate); however, only sodium permanganate will be used for remediation as discussed in Section 4 below.

An example calculation for the shallow zone is presented below to show the basis for the spreadsheet calculations. The spreadsheet calculations are based on the following equation:

$T_R = [(C \times Q_w \times S) + (\text{Effective PNOD} \times Q_s)] \times C_F$

Where:

$T_R$ = Total Oxidant Demand (lb)

C = Contaminant Concentration in Groundwater (mg/l) = 0.075 mg/l

$Q_w$ = Quantity of Water (l)
$Q_w$ = remediation area x saturated thickness x porosity
$Q_w$ =216,000 $ft^2$ x 20 ft x 0.30 x 28.317 L/$ft^3$
$Q_w$ = 36,698,832 L

S = Average Stoichiometric Demand (lb/lb) = 0.96 lb/lb

Effective PNOD = Effective Permanganate Oxidation Demand (g/kg)
Effective PNOD = 1.0 g/kg x 10%
Effective PNOD = 0.1 g/kg

$Q_s$ = Quantity of Soil (lb) = Area ($ft^2$) x Saturated Thickness (ft) x Density of Soil (lb/$ft^3$)

The default value for soil density in the spreadsheet calculation is 1350 kg/CY of 110 lb/ft$^3$.

$C_f$ = Confidence Factor = 5

For RemOx S (potassium permanganate),

$T_R$ = [(0.075 mg/l x 36,698,832 L x lb/454,000mg x 0.96lb/lb) + (0.1g/kg x (216,000 ft$^2$ x 20 ft x CY/27 ft$^3$) CY x 1350kg/CY x lb/454g)] x 5

$T_R$ = 237,915 lbs

For RemOx L (40% sodium permanganate solution), the oxidant demand is derived from the RemOx S demand as follows:

$T_{RemOx\ L}$ = $T_R$ x (mol. wt. $NaMnO_4$/mol. wt. $KMnO_4$) / (0.4 lb $NaMnO_4$ per lb of solution)

$T_{RemOx\ L}$= (237,915 lb x (142g/mole/158g/mole))/ 0.4

$T_{RemOx\ L}$= (237,915 lb x 0.898)/0.4

$T_{RemOx\ L}$ = 534,119 lbs

## . Oxidant Type

Permanganate is available in two forms, namely, potassium and sodium permanganate. Sodium permanganate will be used for remediation at this site based on the following: 1.) The quantity of permanganate solution injected for each injection event would be reduced since potassium permanganate is generally injected at about 2% by weight solution and sodium permanganate is injected at about 5 to 10% by weight solution. This reduction in the volume injected reduces the complexities associated with mixing and transportation of

permanganate and reduces the time required for the injection. This is a distinct advantage in the highly urban remediation area; and 2.) use of sodium permanganate eliminates concerns associated with Homeland Security requirements. In addition, injection of a 5% solution of sodium permanganate significantly reduces health and safety concerns associated with potential human or environmental exposure associated with higher concentrations of sodium permanganate. Carus specifies that spills of sodium permanganate must be diluted to 6% or below to safely neutralize the spill and thereby protect human health and the environment. In general, sodium permanganate solutions are very stable at concentrations of 6% or less and are much safer to work with.

**. Injection Volume**

The calculations presented in Attachment B for all four zones are summarized below.

| Zone | Amount of RemOx L (lb) | Amount of RemOx L (gal of 40% solution) | Amount of RemOx L (gal of 5% solution) |
|---|---|---|---|
| Shallow | 533,477 | 46,673 | 489,020 |
| Intermediate > 100PPB | 1,334,402 | 116,746 | 1,223,198 |
| Intermediate > 1000PPB | 321,093 | 28,092 | 294,335 |
| Deep | 480,228 | 42,015 | 440,208 |

# ATTACHMENT A

Appendix B
Ref. 2

Principles and Practices of

# In Situ Chemical Oxidation Using Permanganate

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**TABLE 2-1. Properties and characteristics of potassium permanganate (CAIROX).[1]**

| Property | Value and/or comments |
|---|---|
| Chemical formula | $KMnO_4$ |
| Purity (% by weight) | Technical Grade = 98%, Free Flowing Grade = 97%, USP Grade = 99% |
| Molecular weight | 158.03 g/mol |
| Form and features | Dark purple solid with metallic luster, sweetest astringent taste, odorless, granular crystalline, oxidizer |
| Specific gravity—solid | 2.703 g/cm$^3$ |
| Specific gravity—6% sol. | 1.039 g/cm$^3$ |
| Bulk density | 90 to 100 lb/ft$^3$ |
| Solubility in distilled water: | |
| 0C | 27.8 g/L |
| 20C | 65.0 g/L |
| 40C | 125.2 g/L |
| 60C | 230.0 g/L |
| Heat of solution | 10.2 Kcal/mole |
| Packaging | 25 kg pail, 50 kg drum, 150 kg drum, plus special packaging |
| Hazardous class (ID no.) | Oxidizer (UN1490) |
| Stability | Stable indefinitely if held in cool dry area in sealed containers |
| Incompatibilities | Avoid contact with acids, peroxides, and all combustible organics or readily oxidizable materials |
| Materials compatibility | In neutral or alkaline conditions $KMnO_4$ is not corrosive to iron, mild steel or stainless steel. However chloride corrosion may be accelerated. Plastics such as polypropylene, PVC, epoxy resins, Lucite, Viton A, and Hypalon are suitable but Teflon FEP and TFE, and Telzel ETFE are best. Natural rubbers and fibers are often incompatible |

[1]Refer to Appendix A for additional manufacturer's information.



available. Sodium permanganate ($NaMnO_4$) is supplied by Carus as a concentrated liquid (min. 40 wt.% as $NaMnO_4$, Table 2-2). In this form, $MnO_4^-$ ion is provided without the potassium (for sites where $^{40}K$ is a concern) and without dusting hazards associated with dry $KMnO_4$ solids.

The composition of potassium permanganate has two facets that are relevant to water quality effects but that are unrelated to in situ o

**TABLE 2-2. Properties and characteristics of sodium permanganate (LIQUOX).[1]**

| Property | Value and/or comments |
|---|---|
| Chemical formula | $NaMnO_4$ |
| Purity | 40.0 % by weight minimum as $NaMnO_4$ |
| Molecular weight | 141.93 g/mol |
| Form and features | Dark purple liquid with metallic luster, sweetest astringent taste, odorless, granular crystalline, oxidizer |
| Specific gravity | 1.36 to 1.39 g/cm$^3$ for a 40% solution |
| Solubility in water | Miscible with water in all proportions |
| Insolubles | 100 to 1900 ppm |
| Potassium | 1000 to 2200 ppm |
| pH | 6.0 to 7.0 |
| Packaging | 18.9L Jerrican, 18.9L steel drum, 208L steel drum |
| Hazard class (ID no.) | Oxidizer (UN3214) |
| Stability | Stable for >18 mon |
| Incompatibilities | Avoid contact with acids, peroxides, and all combustible organics or readily oxidizable materials |
| Materials compatibility | In neutral or alkaline conditions $NaMnO_4$ is not corrosive to carbon and 316 stainless steel. However chloride corrosion may be accelerated. Plastics such as Teflon, polypropylene, HDPE, and EDPM are compatible, but Teflon FEP and TFE, and Telzel ETFE are best |

[1]Refer to Appendix A for additional manufacturer's information.

The stoichiometric reactions for the complete destruction of several common chlorinated organic solvents in an aqueous system are given in eqn. 2.8–2.11.

*Tetrachloroethene (PCE)*

$$4KMnO_4 + 3C_2Cl_4 + 4H_2O \rightarrow 6CO_2 + 4MnO_2 + 4K^+ + 8H^+ + 12Cl^- \quad (2.8)$$

*Trichloroethene (TCE)*

$$2KMnO_4 + C_2HCl_3 \rightarrow 2CO_2 + 2MnO_2 + 2K^+ + H^+ + 3Cl^- \quad (2.9)$$

*Dichloroethene (DCE)*

$$8KMnO_4 + 3C_2H_2Cl_2 \rightarrow 6CO_2 + 8MnO_2 + 8K^+ + 6Cl^- + 2OH^- + 2H_2O \quad (2.10)$$

*Vinyl chloride (VC)*

$$10KMnO_4 + 3C_2H_3Cl \rightarrow 6CO_2 + 10MnO_2 + 10K^+ + 3Cl^- + 7OH^- + H_2O \quad (2.11)$$

Based on the above stoichiometry, the oxidant demand and product formation for chemical oxidation of the four chlorinated ethenes are given in Table 2-4. Note that the reactions are comparable in permanganate demand whether it is supplied in the potassium form or sodium form. As shown in Table 2-4, on a unit mass basis, halocarbons with higher chlorine substitution (e.g., PCE vs. DCE) consume less oxidant (per the stoichiometric requirement) and produce less $MnO_2$ solids.

## Reaction Pathways

The hydroxylation of olefins by $MnO_4^-$ has been known for many years (Wagner 1895). It is generally accepted that under neutral to acidic pHs, $MnO_4^-$ initially reacts with the carbon-carbon double bond to form a five-member cyclic hypomanganate ester (Figure 2-1). That reaction consumes 1 mole of permanganate for each mole of olefin, and that cycloaddition has been reported to be the rate-determining step in degradation (Wiberg and Saegebarth 1957, Stewart 1965, Freeman 1976). Yan and Schwartz (1998, 1999) recently proposed a similar reaction scheme for the chemical oxidation of TCE in which the cyclic ester can then undergo decomposition to carbon dioxide along several oxidative or hydrolysis pathways depending on pH. Several carboxylic acid intermediates including formic, oxalic, glyoxylic and glycolic acids were also identified. In highly alkaline solutions, hydroxyl radicals, which can contribute to oxidative destruction, also may be formed. The degradation

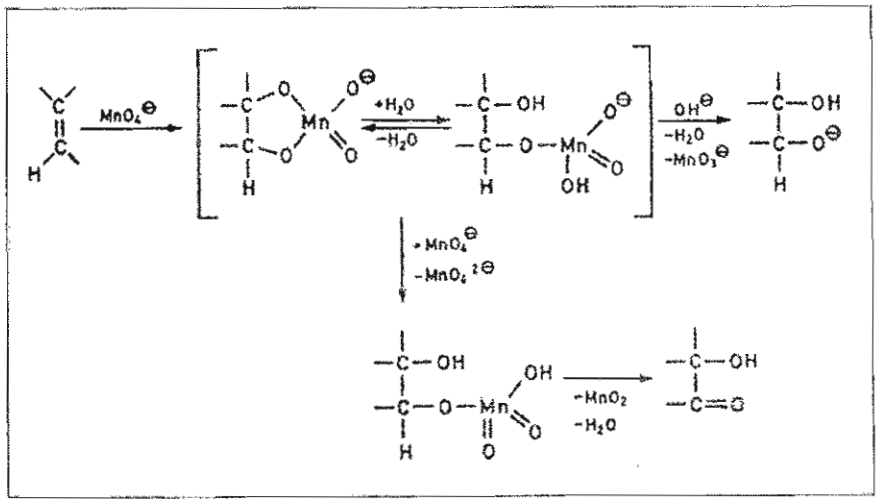


**TABLE 2-4. Stoichiometric requirements for mineralization of organic compounds by permanganate.[1]**

| Target compound | Compound molecular weight (g/mol) | Oxidant demand ($g\ MnO_4^-$ / g of target) | $MnO_2$ produced ($g\ MnO_2$ / g target oxidized) |
|---|---|---|---|
| Tetrachloroethene | 165.6 | 0.96 | 0.70 |
| Trichloroethene | 131.2 | 1.81 | 1.32 |
| Dichloroethene | 96.8 | 3.28 | 2.39 |
| Vinyl chloride | 62.4 | 6.35 | 4.64 |
| Phenol | 94.1 | 11.8 | 8.62 |
| Naphthalene | 128.2 | 14.8 | 10.8 |
| Phenanthrene | 178.2 | 14.7 | 10.7 |
| Pyrene | 202.3 | 14.5 | 10.6 |

[1]Molecular weight of $MnO_4^-$ = 118.9 g, $MnO_2$ = 86.9 g, $KMnO_4$ = 158 g, and $NaMnO_4$ = 141.9 g.

**FIGURE 2-1. Pathway for oxidation of olefins such as TCE.**



# ATTACHMENT B

| SHALLOW | Estimates | Units |
|---|---|---|
| **Treatment Area Volume** | | |
| Length | 60 | ft |
| Width | 3600 | ft |
| Area | 216000 | sq ft |
| Thickness | 20 | ft |
| Total Volume | 160000 | cu yd |
| | | |
| **Soil Characteristics/Analysis** | | |
| Porosity | 30 | % |
| Total Plume Pore Volume | 9694752 | gal |
| Avg Contaminant Conc | 0.075 | ppm |
| Mass of Contaminant | 6.07 | lb |
| PNOD | 1 | g/kg |
| Effective PNOD | 10 | % |
| Effective PNOD Calculated | 0.1 | |
| PNOD Oxidant Demand | 47520 | lb |
| Avg Stoichiometric Demand | 0.96 | lb/lb |
| Contaminant Oxidant Demand | 5.83 | lb |
| Theoretical Oxidant Demand | 47525.83 | lb |
| Confidence Factor | 5 | |
| Calculated Oxidant Demand | 237629.1263 | |
| | | |
| **Injection Volumes for RemOx S** | | |
| RemOx S Injection Concentration | 5.0% | % |
| Total Volume of Injection Fluid | 569,513 | gal |
| Pore Volume Replaced | 0.06 | % |
| **Amount of RemOx S ISCO Reagent Estimated** | | **237,629 pounds** |
| | | |
| **Injection Volumes for RemOx L** | | |
| RemOx L Injection Concentration | 5.0% | % |
| Calculated Specific Gravity | 1.0458115 | g/ml |
| Total Volume of Injection Fluid | 489,020 | gal |
| Pore Volume Replaced | 0.05 | % |
| **Amount of RemOx L ISCO Reagent Estimated** | | **533,477 pounds** |
| | | **46,673 gallons** |

| INTERMEDIATE>100PPB | Estimates | Units |
|---|---|---|
| **Treatment Area Volume** | | |
| Length | 60 | ft |
| Width | 6000 | ft |
| Area | 360000 | sq ft |
| Thickness | 30 | ft |
| Total Volume | 400000 | cu yd |
| | | |
| **Soil Characteristics/Analysis** | | |
| Porosity | 30 | % |
| Total Plume Pore Volume | 24236880 | gal |
| Avg Contaminant Conc | 0.4 | ppm |
| Mass of Contaminant | 80.91 | lb |
| PNOD | 1 | g/kg |
| Effective PNOD | 10 | % |
| Effective PNOD Calculated | 0.1 | |
| PNOD Oxidant Demand | 118800 | lb |
| Avg Stoichiometric Demand | 0.96 | lb/lb |
| Contaminant Oxidant Demand | 77.67 | lb |
| Theoretical Oxidant Demand | 118877.67 | lb |
| Confidence Factor | 5 | |
| Calculated Oxidant Demand | 594388.3507 | |
| | | |
| **Injection Volumes for RemOx S** | | |
| RemOx S Injection Concentration | 5.0% | % |
| Total Volume of Injection Fluid | 1,424,538 | gal |
| Pore Volume Replaced | 0.06 | % |
| **Amount of RemOx S ISCO Reagent Estimated** | | **594,388 pounds** |
| | | |
| **Injection Volumes for RemOx L** | | |
| RemOx L Injection Concentration | 5.0% | % |
| Calculated Specific Gravity | 1.0458115 | g/ml |
| Total Volume of Injection Fluid | 1,223,198 | gal |
| Pore Volume Replaced | 0.05 | % |
| **Amount of RemOx L ISCO Reagent Estimated** | | **1,334,402 pounds** |
| | | **116,746 gallons** |

| INTERMEDIATE>1000PPB | Estimates | Units |
|---|---|---|
| **Treatment Area Volume** | | |
| Length | 60 | ft |
| Width | 1440 | ft |
| Area | 86400 | sq ft |
| Thickness | 30 | ft |
| Total Volume | 96000 | cu yd |
| | | |
| **Soil Characteristics/Analysis** | | |
| Porosity | 30 | % |
| Total Plume Pore Volume | 5816851 | gal |
| Avg Contaminant Conc | 2 | ppm |
| Mass of Contaminant | 97.09 | lb |
| PNOD | 1 | g/kg |
| Effective PNOD | 10 | % |
| Effective PNOD Calculated | 0.1 | |
| PNOD Oxidant Demand | 28512 | lb |
| Avg Stoichiometric Demand | 0.96 | lb/lb |
| Contaminant Oxidant Demand | 93.20 | lb |
| Theoretical Oxidant Demand | 28605.20 | lb |
| Confidence Factor | 5 | |
| Calculated Oxidant Demand | 143026.0208 | |
| | | |
| **Injection Volumes for RemOx S** | | |
| RemOx S Injection Concentration | 5.0% | % |
| Total Volume of Injection Fluid | 342,783 | gal |
| Pore Volume Replaced | 0.06 | % |
| **Amount of RemOx S ISCO Reagent Estimated** | | **143,026 pounds** |
| | | |
| **Injection Volumes for RemOx L** | | |
| RemOx L Injection Concentration | 5.0% | % |
| Calculated Specific Gravity | 1.0458115 | g/ml |
| Total Volume of Injection Fluid | 294,335 | gal |
| Pore Volume Replaced | 0.05 | % |
| **Amount of RemOx L ISCO Reagent Estimated** | | **321,093 pounds** |
| | | **28,092 gallons** |

| DEEP | Estimates | Units |
|---|---|---|
| **Treatment Area Volume** | | |
| Length | 60 | ft |
| Width | 2160 | ft |
| Area | 129600 | sq ft |
| Thickness | 30 | ft |
| Total Volume | 144000 | cu yd |
| | | |
| **Soil Characteristics/Analysis** | | |
| Porosity | 30 | % |
| Total Plume Pore Volume | 8725277 | gal |
| Avg Contaminant Conc | 0.2 | ppm |
| Mass of Contaminant | 14.56 | lb |
| PNOD | 1 | g/kg |
| Effective PNOD | 10 | % |
| Effective PNOD Calculated | 0.1 | |
| PNOD Oxidant Demand | 42768 | lb |
| Avg Stoichiometric Demand | 0.96 | lb/lb |
| Contaminant Oxidant Demand | 13.98 | lb |
| Theoretical Oxidant Demand | 42781.98 | lb |
| Confidence Factor | 5 | |
| Calculated Oxidant Demand | 213909.9031 | |
| | | |
| **Injection Volumes for RemOx S** | | |
| RemOx S Injection Concentration | 5.0% | % |
| Total Volume of Injection Fluid | 512,666 | gal |
| Pore Volume Replaced | 0.06 | % |
| **Amount of RemOx S ISCO Reagent Estimated** | | **213,910 pounds** |
| | | |
| **Injection Volumes for RemOx L** | | |
| RemOx L Injection Concentration | 5.0% | % |
| Calculated Specific Gravity | 1.0458115 | g/ml |
| Total Volume of Injection Fluid | 440,208 | gal |
| Pore Volume Replaced | 0.05 | % |
| **Amount of RemOx L ISCO Reagent Estimated** | | **480,228 pounds** |
| | | **42,015 gallons** |

# APPENDIX B

# COST ESTIMATES

West Side Corp OU2 FFS
Permanganate Injection

# Construction Cost Estimate

**Bases**

(1) Performance Monitoring - After each of 2 injection events for Alt 2A and 3 injection events for Alts 2B and 2C, perform 5 rounds of monitoring, one round per each of 5 months then a round of VOCs, metals and alkalinity.

(2) Baseline Monitoring - Baseline monitoring shall be done to supplement the program completed in Fall 2012.

(3) Injection Events - Two (2) injection events to be performed for Alt 2A, 3 events for Alts 2B and 2C

(4) Permanganate - Inject at 5% solution (Oser OU2 was 20% solution).

(5) Assume Alt 2B and 2C are essentially "same"in terms of number of wells and performance monitoring effort, given the assumptions noted and level of accuracy noted within the individual unit pricing and costs derived herein.

(6) Thus the main differences between all Alts are permanganate volumes for each Alt; and the performance monitoring for Alt 2A versus 2B/2C.

(7) Well depth per Table 4-1 (attached):
Shallow = 30 ft bgs
Intermediate = 60 ft bgs
Deep = 90 ft bgs

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| | | | |
|---|---|---|---|
| | | By: RJP | Cked By: AMM |
| | | Date: 2/19/2013 | Date: 2/21/2013 |

| **Bid Item** | **Description of Bid Item** | **Unit of Measure** |
|---|---|---|
| UC-1 | Site Services | Day |

Limited to 5% of bid amount per Measurement and Payment spec

Total of cost items exclusive of

| | | |
|---|---|---|
| | UC-1 | Site Services |
| and | LS-1 | Mob/Demob & Site Prep |

which are the two "limited to 5% of bid amount items"

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-2a | Injection Well Installation - Nest of Two | LF |

The basis for this item is Item UC-4 Monitoring Well Installation (Singles), 2-in diam, which will be installed via HSA method at 6-inch diameter. Injection wells will be installed via sonic method and will be two 1-inch risers installed into an 8-inch diameter borehole.

Cross section area A: 6-inch diam = (pi)(3 in.)$^2$ = 28.3 sq. in.
8-inch diam = (pi)(4 in.)$^2$ = 50.2 sq. in. or approx. double the 6-in. dia.

Thus the net adds for sonic drilling are as follows:

(a) (8-inch sonic drilling) minus (6-inch HSA drilling) = ($40/LF) - ($20/LF) = $20/LF
See attached unit pricing from driller for these unit prices.

(b) PVC well labor and materials: Assume it is 1.5 (x $18) that of single well = $ 27/LF

(c) Cuttings are minimized to negligible due to using sonic method so cuttings volume is actually decreased compared to that of 6-inch HSA boring. Ignore cost reduction of cuttings to be conservative.

(d) Total add-on $ 47/LF
(e) Monitoring Well unit price plus $ 200/LF

TOTAL $ 247/LF

say $250/LF

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-2b | Injection Well Installation - Nest of Three | LF |

Use UC-2a Injection Well Installation - Nest of Two, as cost basis.
Nest of three will also be constructed in 8-inch diameter bore hole via sonic method.

Thus, use Nest of Two and add $18/LF to account for additional riser:

| | |
|---|---|
| Nest of Two unit cost | $250/LF |
| Add for add'l riser | $18/LF |
| SUB-TOTAL 1 | $268/LF |

To account for management of traffic (MOT) add $30,000

| | | |
|---|---|---|
| $30,000/(80 wells x 40 LF) = | $9/LF | SUB-TOTAL 2 |

TOTAL = $277/LF

say $280/LF

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-2c | Injection Well Installation - Single | LF |

See Cost Summary and unit price derivation for Injection Wells Doubles and Triples. There is minor difference between unit price for doubles and triples. Doubles are about 10% lower unit price than triple.

Double and triples are assumed to both be installed in 8-inch diameter borehole so most of cost is in the drilling aspect. Singles may be able to be installed in smaller diameter bore hole but, for this level estimate, assume singles are also installed in 8-inch diameter bore hole.

Say, single unit price is 10% less than double unit price:

Single = (0.90) x ($250/LF) = $ 225 per LF

compare to OSER bids this is too high; look at OSER bids and use avg

say $170/LF

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| | | | |
|---|---|---|---|
| | | By: RJP | Cked By: AMM |
| | | Date: 2/19/2013 | Date: 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-3 | Sodium Permanganate Injection | Gallon |

Kliegman estimate was approx $4.50/gallon for 5% sodium permanganate solution injected.

| | | | |
|---|---|---|---|
| Recent Carus estimate for permanganate delivered reported at | | $3.50 | per gallon |
| Add for injection | this site | $2.00 | per gallon |
| | TOTAL | $5.50 | per gallon |

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/13/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-4 | Monitoring Well Installation (Singles) | LF |

**Stuart Olver-Holtz**

Ref Stuart Olver-Holtz (DEC) site with similar construction and approx 30-ft deep = $161/LF

**Oser OU2**

Oser OU2 mon wells per dwg C-005

| | |
|---|---|
| SPMW-01 | 64 LF |
| SPMW-02 | 45 LF |
| SPMW-03 | 46 LF |
| SPMW-04 | 23 LF |
| SPMW-05 | 31 LF |
| SPMW-06 | 9 LF |

avg 36 LF

**West Side:** Assume Two monitoring well "clusters" at 3 individual wells each.

That is, drill 6 individual wells.

Well depth about 90 feet bgs:

(6 wells) x (90 ft) = 540 LF

Assume 25% premium to drill to 90 ft bgs. Drillers usually quote pricing for 0 to 50 ft then 50 to 100 ft bgs, etc.

Use $161/LF plus 50% = $ 201

say $200/LF

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-5 | Health and Safety | Day |

Ref. vendor quote (attached)

$250/day

Oser OU2 basis was for 300 days to address well construction plus injection events.

Alt 2A will have about same number of wells (60) but one less injection event
(2 events instead of 3). So use about 300 days for West Side Alternative 2A

Alt 2B will have more wells (84) and the same (3) injection events
So use about 450 days for West Side Alternative 2B

Alt 2C will have more wells (196) and the same (3) injection events
So use about 750 days for West Side Alternative 2C
(Note that multiple crews are included for Alternative 2C)

West Side Corp OU2 FFS
Permanganate Injection
Unit Pricing

| | | | |
|---|---|---|---|
| | | By:<br>Date: | Cked By:<br>Date: |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-6 | NOT USED | LF |

NOT USED

West Side Corp OU2 FFS
Permanganate Injection
Unit Pricing

| | | | |
|---|---|---|---|
| | | By:<br>Date: | Cked By:<br>Date: |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-7a | NOT USED | LF |

NOT USED

West Side Corp OU2 FFS
Permanganate Injection
Unit Pricing

| | | | |
|---|---|---|---|
| | | By:<br>Date: | Cked By:<br>Date: |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| UC-7b | NOT USED | LF |

NOT USED

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| | | | |
|---|---|---|---|
| | | By: RJP | Cked By: AMM |
| | | Date: 2/19/2013 | Date: 2/21/2013 |

| **Bid Item** | **Description of Bid Item** | **Unit of Measure** |
|---|---|---|
| LS-1 | Mob/Demob & Site Prep | Lump Sum |

Limited to 5% of bid amount per Measurement and Payment spec

Total of cost items exclusive of

| | | |
|---|---|---|
| | UC-1 | Site Services |
| and | LS-1 | Mob/Demob & Site Prep |

which are the two "limited to 5% of bid amount items"

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| LS-2 | Site Survey | Lump Sum |

**Oser OU2 Take-Off:**

Refer to attached price quote from Naik Group

Services include the following:

1. Establish survey control
2. Pre-stakeout of 60/84/196 proposed injection wells, 6 new monitoring wells
3. Surficial features locating
4. Public right-of-ways
5. Locate as-built x-y-z of constructed wells
6. Base map preparation
7. "Normal" constr. Coord. with Prime Contractor, Engineer, and Municipalities
8. Typical construction submittals such as electronic files and field notes

Cost Quote = $57,900

**West Side:**

West Side preliminary design consists of about 60/84/196 proposed injection wells plus 6 new monitoring wells, (compared to 60 for Oser OU2).
All other tasks for West Side should be similar to Oser OU2 so use Oser OU2 estimate for West Side.

| | | |
|---|---|---|
| Say | $60,000 | 2A, 2B |
| | $75,000 | 2C |

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing

| By: | RJP | Cked By: | AMM |
|---|---|---|---|
| Date: | 2/19/2013 | Date: | 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| LS-3a | Baseline Monitoring | Lump Sum |

**Oser OU2 Basis:**

Average bid was $64,000 and entire project low bidder was $79,000.

This involved: 55 lab samples from 45 locations (mon wells, surface water, sed.)
plus 35 field test locations

**West Side OU2:**

West Side involves 54 samples from 19 locations.

This plan is very similar to Oser OU2 so can expect $65k to $80K.

say $80,000

| | | |
|---|---|---|
| | By: RJP<br>Date: 2/19/2013 | Cked By: AMM<br>Date: 2/21/2013 |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| LS-3b | Performance Monitoring | Lump Sum |

**Oser OU2 Basis:**

Average bid was $272,000 and entire project low bidder was $227,000.
This involved 20 trips and 73 wells @ various depths for total of 125 sample intervals per trip.

**West Side OU2:**

West Side planned to consist of 12 trips and 60 - 80 wells @ various depths for total of
100 to 140 sample intervals per trip for Alts 2A and 2B

Since West Side # wells and # samples is about same as Oser OU2, we can assume
that West Side is about same as Oser OU2 in this regard for Alts 2A and 2B
However, West Side # trips is about 2/3 that of Oser OU2 for Alt 2A

| | | |
|---|---|---|
| Thus, assume West Side cost = (2/3) x ($250,000) = | $ 165,000 | Alt 2A |
| | $250,000 | Alt 2B |
| (Alt 2C is about triple this effort in terms of manhours, per back-up; and double in terms of # samples per backup. Thus, say Alt 2C cost is triple of that shown above. | $750,000 | Alt 2C |

West Side Corp OU2 FFS
Permanganate Injection
Unit Pricing

| | |
|---|---|
| By: | Cked By: |
| Date: | Date: |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| LS-3c | NOT USED | Lump Sum |

NOT USED

West Side Corp OU2 FFS
Permanganate Injection
Unit Pricing

| | | | |
|---|---|---|---|
| | | By:<br>Date: | Cked By:<br>Date: |

| Bid Item | Description of Bid Item | Unit of Measure |
|---|---|---|
| LS-4 | NOT USED | Lump Sum |

NOT USED

# DRAFT

Table 5-1

Alterna ives 2A, 2B, 2C Cost Estimates

| | | | UNIT PRICES | | | ALT 2A | | ALT 2B | | ALT 2C | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ITEM NO. | DESCRIPTION | UNIT | UNIT PRICE FROM ATTACHED BACK-UP | AVG UNIT PRICE FROM OSER OU2 BIDS | UNIT PRICE FROM OSER OU2 LOW BIDDER | EST QTY | TOTAL PRICE ($) | EST QTY | TOTAL PRICE ($) | EST QTY | TOTAL PRICE ($) |
| UC-1 | Site Services | Day | NA | $ 286 | $ 150 | 1 | $ 179,552 | 1 | $ 281,714 | 1 | $ 758,127 |
| UC-2a | Injection Well Installation - Nest of Two | LF | 250 | $ 171 | $ 115 | | $ - | | | | |
| UC-2b | Injection Well Installation - Nest of Three | LF | 280 | $ 170 | $ 120 | | $ - | | $ - | | $ - |
| UC-2c | Injection Well Installation - Single | LF | 230 | $ 170 | NA | 1,800 | $ 305,233 | 3,240 | $ 549,419 | 11,040 | $ 1,872,095 |
| UC-3 | Sodium Permanganate Injection | Gallon | $5.50 | $ 12 | $ 11 | 500,000 | $ 2,750,000 | 800,000 | $ 4,400,000 | 2,175,000 | $ 11,962,500 |
| UC-4 | Monitoring Well Installation (Singles) | LF | 200 | $ 190 | $ 135 | 540 | $ 102,708 | 540 | $ 102,708 | 540 | $ 102,708 |
| UC-5 | Health and Safety | Day | 250 | $ 427 | $ 283 | 300 | $ 128,098 | 450 | $ 192,148 | 750 | $ 320,246 |
| UC-6 | NOT USED | LF | 0 | $ - | $ - | | $ - | | $ - | | $ - |
| UC-7a | NOT USED | LF | 0 | $ - | $ - | | $ - | | $ - | | $ - |
| UC-7b | NOT USED | LF | 0 | $ - | $ - | | $ - | | $ - | | $ - |
| LS-1 | Mob/Demob & Site Prep | Lump Sum | 179,552 | $ 179,936 | $ 271,803 | 1 | $ 179,552 | 1 | $ 281,714 | 1 | $ 758,127 |
| LS-2 | Site Survey | Lump Sum | 60,000 | $ 23,438 | $ 37,114 | 1 | $ 60,000 | 1 | $ 60,000 | 1 | $ 75,000 |
| LS-3a | Baseline Monitoring | Lump Sum | 80,000 | $ 64,000 | $ 79,000 | 1 | $ 80,000 | 1 | $ 80,000 | 1 | $ 80,000 |
| LS-3b | Performance Monitoring | Lump Sum | 250,000 | $ 272,000 | $ 226,000 | 1 | $ 165,000 | 1 | $ 250,000 | 1 | $ 750,000 |
| LS-3c | NOT USED | Lump Sum | 0 | $ - | $ - | 0 | $ - | | $ - | | $ - |
| LS-4 | NOT USED | Lump Sum | - | $ - | $ - | 0 | $ - | | $ - | | $ - |
| | | | | SUBTOTAL | | | $ 3,950,143 | | $ 6,197,702 | | $ 16,678,803 |
| | | | | CONTINGENCY (15% of Subtotal) | | | $ 592,521 | | $ 929,655 | | $ 2,501,821 |
| | | | | GRAND TOTAL | | | $ 4,542,664 | | $ 7,127,357 | | $ 19,180,624 |

Highlighted item = 5% of total of all non-hilighted items

Highlighted item = selected unit price for this estimate

Highlighted item only shown for illustration and not necessarily for direct comparison as scope of such items may be different for different projects

# West Side Corp OU2 FFS
# Permanganate Injection
# Unit Pricing Back-Up

By: GK
Date: 8/10/2011

**Average cost for:**

| | | |
|---|---|---|
| TCL VOC by SW846-8260B | = | $ 67 |
| TAL Metals by SW846-6010B/7470A/7471A | = | $ 96 |
| Alkalinity by EPA 310 | = | $ 13 |
| Total | | $176 |

Lab Color by SM 2120B …….…….. $11

(Add sample frequency of 5% for Baseline testing for MS/MSD's … i.e., 5% mark-up)

**Average Turnaround Time premium**

24 hour = 89%
48 hour = 62%
72 hour = 40%
1 week = 18%
2 week = 7%

Averages based on 9 bid responses for NYSDEC Standby Contract D007622, May 2011, rounded up to the nearest dollar. Prices for soil and water are the same.
NYSDEC ASP Category B deliverables

West Side Corp OU2 FFS
Permanganate Injection

# Performance Monitoring

> Mon/Sampling Table
> Man-Hour Estimate

| | | | | ALT 2A | | | ALT 2B | | | ALT 2C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | # | Depth (ft) | Length (LF) | # | Depth (ft) | Length (LF) | # | Depth (ft) | Length (LF) |
| **Injection wells at 60-foot intervals** | | | | | | | | | | | | |
| | Shallow | Intermediate | Deep | | | | | | | | | |
| Along 177th St | | | | | | | | | | | | |
| 109th - 110th (600 ft) | 11 | 11 | | 11 | 30 | 330 | 11 | 30 | 330 | 22 | 30/60 | 990 |
| 110th - 111th (600 ft) | 5 | 5 | | 5 | 30 | 150 | 5 | 30 | 150 | 10 | 30/60 | 450 |
| | | | | | | | | | 0 | | | |
| Along 176th St | | | | | | | | | 0 | | | |
| 109th - 110th (600 ft) | 11 | 11 | | 11 | 30 | 330 | 11 | 30 | 330 | 22 | 30/60 | 990 |
| 110th - 111th (600 ft) | 11 | 11 | | 11 | 30 | 330 | 11 | 30 | 330 | 22 | 30/60 | 990 |
| | | | | | | | | | 0 | | | |
| Along 175th St | | | | | | | | | 0 | | | |
| 110th - 111th (600 ft) | 11 | 11 | | 11 | 30 | 330 | 11 | 30 | 330 | 22 | 30/60 | 990 |
| 110th - 111th (420 ft) | | | 8 | | | | | | 0 | 8 | 90 | 720 |
| | | | | | | | | | 0 | | | |
| Along 174th St | | | | | | | | | 0 | | | |
| 110th - 111th (600 ft) | 11 | 11 | | 11 | 30 | 330 | 11 | 30 | 330 | 22 | 30/60 | 990 |
| 110th - 111th (300 ft) | | | 5 | | | | | | 0 | 5 | 90 | 450 |
| 111th - 112th (600 ft) | | 10 | 10 | | | | | | | 20 | 60/90 | 1500 |
| | | | | | | | | | 0 | | | |
| Along 111th (300 ft) | | | | | | | | | 0 | | | |
| 172nd - 173rd | | 6 | | | | | | | 0 | 6 | 60 | 360 |
| | | | | | | | | | 0 | | | |
| Along Sayres (W to E) | East of Merrick Blvd | | | | | | | | 0 | | | |
| 250 ft | | 5 | 5 | | | | 5 | 60 | 300 | 10 | 60/90 | 750 |
| 200 ft | | 4 | 4 | | | | 4 | 60 | 240 | 8 | 60/90 | 600 |
| 200 ft | | 4 | 4 | | | | 4 | 60 | 240 | 8 | 60/90 | 600 |
| | | | | | | | | | 0 | | | |
| Along Sayres (W to E) | West of Merrick Blvd | | | | | | | | 0 | | | |
| 200 ft | | 4 | | | | | 4 | 60 | 240 | 4 | 60 | 240 |
| 200 ft | | 4 | | | | | 4 | 60 | 240 | 4 | 60 | 240 |
| 150 ft | | 3 | | | | | 3 | 60 | 180 | 3 | 60 | 180 |
| | | | | 60 | | 1800 | 84 | | 3240 | 196 | | 11040 |
| | **Shallow** | **Intermediate** | **Deep** | | | | | | | | | |
| **TOTALS** | **60** | **100** | **36** | | | | | | | | | |

Note: Spacing at 60-foot intervals refers to a 30-foot radius of influence

| | | | |
|---|---|---|---|
| Well Screen Depths: | Shallow: 12 - 22 feet bgs | Intermediate: 35 - 45 feet bgs | Deep: 70 - 80 feet bgs |
| Groundwater zones | Shallow: 10 - 30 feet bgs | Intermediate: 30 - 60 feet bgs | Deep: 60 - 90 feet bgs |

**ALTERNATIVE 2A -** 60 SHALLOW INJECTION WELLS
**ALTERNATIVE 2B -** 60 SHALLOW AND 24 INTERMEDIATE INJECTION WELLS ALONG SAYRES AVE
**ALTERNATIVE 2C-** 60 SHALLOW AND 100 INTERMEDIATE AND 36 DEEP INJECTION WELLS

| Alternative 2A | | | | | | |
|---|---|---|---|---|---|---|
| | # of Injection Wells | Gallons 5% Permanganate Solution | @ 8 gpm required injection hrs per well | Productivity Reduction | # of Injection Events | Manhours per Injection Event (assume 2 person crew) |
| Shallow | 60 | 500,000 | 18 | 0.75 | 2 | 1,440 |
| Intermediate | | | | | | |
| Deep | | | | | | |

| Alternative 2B | | | | | | |
|---|---|---|---|---|---|---|
| | # of Injection Wells | Gallons 5% Permanganate Solution | @ 8 gpm required injection hrs per well | Productivity Reduction | | Manhours per Injection Event (assume 2 person crew) |
| Shallow | 60 | 500,000 | 18 | 0.75 | 2 | 1,440 |
| Intermediate | 24 | 300,000 | 27 | 0.75 | 3 | 576 |
| Deep | | | | | | |

| Alternative 2C | | | | | | |
|---|---|---|---|---|---|---|
| | # of Injection Wells | Gallons 5% Permanganate Solution | @ 8 gpm required injection hrs per well | Productivity Reduction | # of Injection Events | Manhours per Injection Event (assume 2 person crew) |
| Shallow | 60 | 500,000 | 18 | 0.75 | 2 | 1,440 |
| Intermediate | 100 | 1,225,000 | 26 | 0.75 | 3 | 2,312 |
| Deep | 36 | 450000 | 27 | 0.75 | 3 | 864 |

| Frequency of Groundwater Sample Collection | Baseline Monitoring Prior to 1st Injection Event | | | | | | Prior to 2nd Injection Event | | | | | | Prior to Subsequent Injection Events |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameters | | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 (approx) | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 (approx) |
| VOCs, Metals, Alkalinity | x | | | | | | x | | | | | | x |
| Color | | x | x | x | x | x | x | x | x | x | x | x | x |
| Field Parameters (pH, DO, ORP, Specific Conductivity) | x | x | x | x | x | x | x | x | x | x | x | x | x |

| Baseline Monitoring | Shallow | Intermediate | Deep |
|---|---|---|---|
| W-01 | S | I | D |
| W-02 | S | I | D |
| W-03 | S | I | D |
| W-04 | S | I | D |
| W-05 | S | | |
| W-06 | S | I | D |
| W-07 | S | I | D |
| W-08 | S | I | D |
| W-09 | S | I | D |
| W-10 | S | I | D |
| W-11 | | I | D |
| W-12 | S | I | D |
| W-13 | S | I | D |
| W-14 | S | I | D |
| W-15 | S | I | D |
| MW-24-5 | S | I | D |
| MW-24-6 | S | I | D |
| New Monitoring Well P1 | S | I | D |
| New Monitoring Well P2 | S | I | D |
| Totals | 18 | 18 | 18 |
| **Total # of Groundwater Samples** | | | **54** |
| **Total # of Sampling Locations** | | | **19** |

| Prior to Injection Events | Shallow | Intermediate | Deep | Total # of Samples | Total # of Sample Locations |
|---|---|---|---|---|---|
| Baseline Monitoring Wells | 18 | 18 | 18 | 54 | 19 |
| Alternative 2A | 60 | | | 114 | 79 |
| Alternative 2B | 60 | 24 | | 138 | 103 |
| Alternative 2C | 60 | 100 | 36 | 250 | 132 |