

Optimization of CO₂ Storage in Saline Aquifers using the Raven Software

%DUKDP 6 0DKPRRG

,QVWLWXWH RI 3HWUROHXP (QJLQHHULQJ +HULRW :D

&RUUHVSRRGLQJ DXWKRU %DUKDP 6 0DKPRRG ,QVWLWXWH RI 3HWUROHXP (QJLQHHULQJ +HULRW :D
(PDEOUKDP VDELU#NR\DXQLYHUVLW\ RUJ

5HFHLYHG GDWH \$XJ 1\$RFHSHWG 6XDEHLV\KIFG GDWH

&RS\ULJKW 0DKPRRG %6 7KLV LV DQ RSHQ DFFHVV DUWLFOH GLVWULEXWHG XQGHU WKH WHUPV RI WKH
XVH GLVWULEXWLRQ DQG UHSURGXFWRQ LQ DQ\ PHGLXP SURYLGHG WKH RULJLQDO DXWKRU DQG VRXU

\$EVWUDFW

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GXH WR WKH FRQVLGHUDEOH XQFHUWDLQLHV WKDW VWLOO H[LWV UHJDUGLQJ
EHFDXVH WKLV LV DQ H[SHQVLYH SURFHVV VRD\QSRQH HHOHZVW WKLQ VWRUDJH
IRUPDWLRQ +RZHYHU LQMHFW LQVWRUDJH DQ FDSDFLW\ XQD\ VDOLQH IRUPDWLRQ SRV
LVVXH VXFK DV SUHVXUH FDSDFLW\ XSDJH LQ RUGHU WR IXOO\ H[SORLW LW LV
VWUDWHJLHV QHHG WR EH LQYHVWLJDWHG ,Q WKLV SDSHU ZH H[DPLQH D UHDOL
RSWLPL]DWLRQ VWXG\ RQ VRPH VLPXODWLRQ SDUDPHWHUV E\ DSSO\ LQJ PXOWL RE
02362 WR (QDQVWRUDJH FDSDFLW\ DQG VDIHW\ E\ 0DQLPH]WRUDJH VWRUDJH
EXLOG XS LQ WKH FHQWHU RI WKH DSDUHQW DQ GWKHUHQPHYR&2WKH DTXLIHU

7KH UHVXOW RI WKLV VWXG\ VKRZV WKDW ZKHQ FDKQJLQJ WKH QXPEHU RI ZHOOR
FDSDFLW\ IRU GRPH \$ LV LQFUHDVHG E\ 0HBYHU UGLW KHUHQPHYR&2WKH FULWHU
\HDU 7KH UHVXOWV DOVR LQGLFDWH WKDW WKH 02362 DOJRULWKP LV SURPLVLQJ
VWRUDJH FDSDFLW\ VLJQLILFDQWO\ ZKLOH UHFRUGLQJ WKH SUHVXUH EXLOG XS DQ

.H\ZRUGV H6DQXIHU 6WRUDJH ULVN 3UHVXUH EXLOG XS 02362

,QWURGXFWRQ

\$V WKH OHYHO RYHU \HDU\ QD VWRUDJH DU\ WR
WR WKLV SUREOHP &DUERQH FDSWXUH DQG VWRUDJH &&6 LV FRQVLGHUHG WR
EH DQ LPSRUWDQW PHDQV RI DHEXPH\ WKH OHYHO RI &2 FRFTM

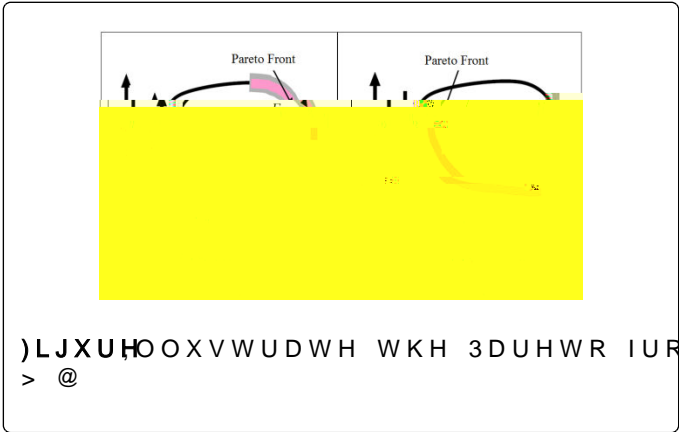
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 ORFDWLRQ RI SDUWHLFOH ORFDWLRQ RQGHUHG DY D SBLQW
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 EHHQ HYDOXDWHG DV D SUREOHP VROXWLR ORFDWLRQ
 EHWWHU WKDQ DOO WKH IRVWHODERUHG RQW
 EHHQ VWRUHG LQ WKH SVHYORXV FDOOHG LQ
 XVHG IRU FRPSDULVRQ LQ WKH QH[W LWHU REMHFWLY
 FRQWLQXRXV DQGEHDWFKU WRRFDVQSDUMR WK
 XSGDWHG E\ DGGLQJ D QHWRFRUHG QDQVWKHRP 9
 HTXDWLRQHUBLDGDRWKHU EHVW YDOXH)LJXUH 3.2 WKH RYHUDOO EHVW YDOXH WKH VWDWLF
 E\ JOREDO YHULYDO RYHUDOO EHVW YDOXH DQG EHVW
 ORFDWLRQ ZKLFK LV REWDLQHG E\ HQGLYLGXDO LQ WKH SRSXODWLRQ VR IDU
 YDOXH EDQOHG *

3URSHUWLHV 8QLWH 9DOXH

OXOWL REMHFWLYH SDUWHLFOH VZDUP RSWLPLJH DWLRQ WWHV
 ,Q WKH VLQJOH REMHFWLYH SDUWHLFOH VZDUP RSWLPLJH DWLRQ WKH PDLQ JRDO L
 WR RSWLPLJH D VLQJOH REMHFWLYH IXQFWLRQ DQG GHWHUPLQH WKH RYHUDOO
 RSWLPLXP YDOXH IRU WKDW REMHFWLYH VZDUP RSWLPLJH WKH
 REMHFWLYH SDUWHLFOH VZDUP RSWLPLJH DWLRQ LV PRUH FRPSOH[,Q 02362 WKH
 PDLQ SXUSRVH LV WR DGHRFWRU DZKLFK LV
 UHSUHVHQWLQJ WKH EHVW SRVVLEOH FRPSURFHVV DWLRQ WKH YDULRXV
 REMHFWLYHV WKLV LV FDOOHG 3DUHWR IURQW > @ 3DUHWR IURQW FDQ EH
 D EHVW SRVVLEOH VROXWLRQ ,Q RWKHU ZRUGV 3DUHWR IURQW LV D VHW
 FRQWDLQV DOO WKH REMHFWLYH YHFWRUV SUHODWLRQV WKH SDUDPHWHU YHFWRU
 KDYH QRW EHHQ GRPLQDWHG E\ DQ RWKHU SDUDPHWHU YHFWRUV > @ +RZHYHU
 ZKHQ WKH SDUDPHWHU YHFWRUV GRPLQDWHG E\ DQRWKHU RQH WKLV SDUDPHWHU
 YHFWRU LV FDOOHG UHPDLQHU)LJXUH \$ VKRZV WKH 3DUHWR IURQW IRU WZR
 REMHFWLYHV PDLQDWLRQ SUREOHPV DQG)LJXUH % VKRZV WKH 3DUHWR
 IURQW IRU WZR REMHFWLYHV SRVLPHDWLRQ SUREOHPV
 ZKLFK RSWLPLJH I DQG I DUH DOVR GHPRQVUDWHG LQ WKH)LJXUH

5HVHUYRLU 'HVFULSWLRQ ORGHO

%XQWHU VDQGVWRQH IRUPDWLRQ PRGHO IURP (7, 8. 6\$3 KDV EHHQ
 XVHG DV D W\SLFDO VDOHQH VDOHQH VDOHQH VDOHQH VDOHQH
 VWUXFWXUH RI %XQWHU VDQGVWRQH FRQWDLQV IRXU GRPHV \$ % & ' DV
 VKRZQ LQ)LJXUH DQG PRVW ROZWKHWHGRHV KDYH EHHQ
 ZDWHU %XQWHU) PDLQDWLRQ SUREOHPV WKH SDUDPHWHU YHFWRU KLJK DQG ORZ
 SRURVLW\ DQG SHUPLWLOO SWRSHUWLHV RI %XQWHU IRUPDWLRQ
 ZKLFK DUH XVHG LQ JHRORJLFDO PRGHO DUH VXPPDULJHG LQ 7DEOH
 GHWDLOHG PRGHO RI UHVHUYRLU SURSHUWLHV DQG FKDUFWHULVWLFV RI WK
 IRUPDWLRQ DUH SURYLGHG LQ :LOOLDPV HW DO > @



)LJXUH HOXVWUDWH WKH 3DUHWR IURQW VHW IRU OXOWL REMHFWLYH IXQFWLRQ
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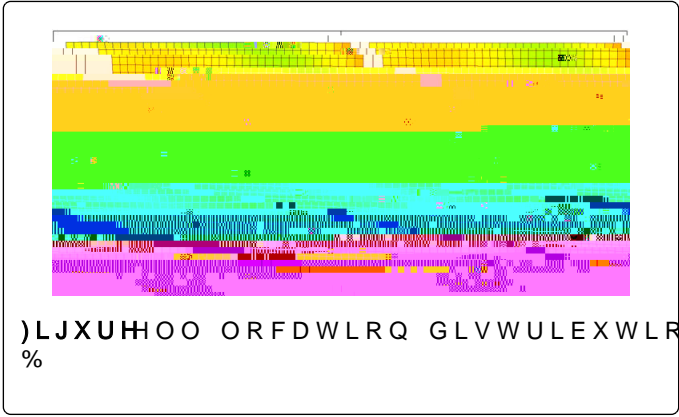
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 GHFLVLRQ PDNHU '0 WR PDNH D SURSIKQ FWHFRQV RQ E ERW SORQH ZLGHU
 UDQJH RI VROXWLRQV)URP HQJLQHHULQJ SRLQW RI YLHZ SDUHWR IURQW FDQ
 DOVR EH XVHIXO EHFDXVH LW JLYHV D EHWWHU XQGHUVWDQGLQJ RI RYHUDOO V\

&DVH RQH		
3DUDPHWHUV	:HOO QDPH	5DQJH
,QMHFWRQ GDWZHQQ)URP , WR ,	i ± i
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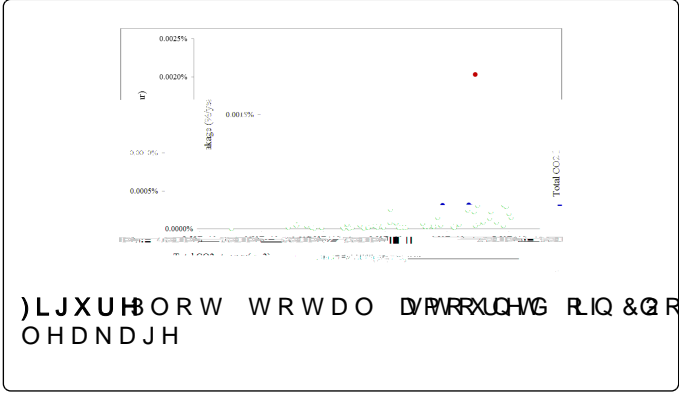
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3DUDPHWHUV	:HOO QDPH	5DQJH
,QMHFWRQ GDWZHQQ)URP , WR ,	i i
:HOO ORFDWLRQ LQ ; GLUHFWLRQ	,	
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:HOO FRPSOHWRQ)URP , WR ,	

)LJXUH LOOXVWUDWH WKH SDUHWR IURQW IRU WZR REMHFWLYH SUREOHPV WF
DPRXQW MWJHG LQ 'RPH \$ 5*,~~3H~~DNQJHWRWDO &2
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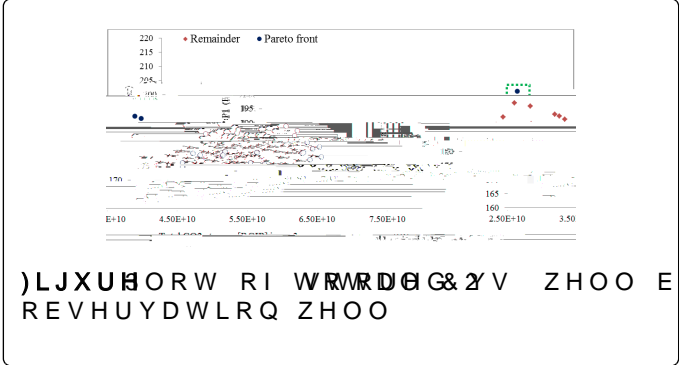
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EXW WKH UHVW DUH EHZRZ WLVHVPD KLPZOH HQHUVQHUBWHLPLWLJXUH RQFH DJDLQ V
)LJXUH WRWDO W&RUDJH DQG DWRDWHUHQDWH ,Q FRQ



)LJXUHOO ORFDWLRQ GLVWULEXWLRQV LQ GRPH \$ IRU VROXWLRQV \$ DQG %



)LJXUBORW WRWDO DWRDWH RI Q&RPH \$ YV &2
OHDNDJH



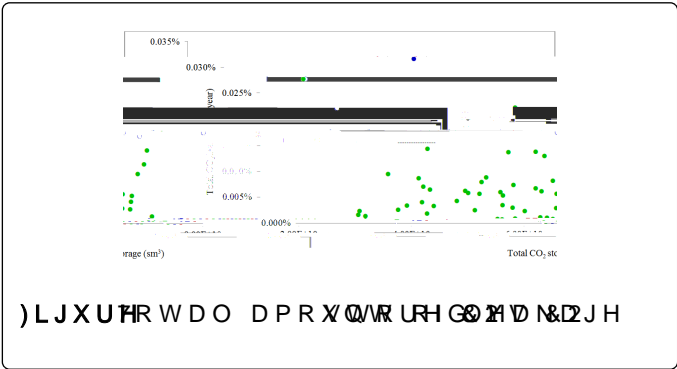
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REVHUYDWLRQ ZHOO

,Q)LJXUH WKH REMHFWLYH SUREOHPV RI ZHOO ERWWRP KROH SUHVXUH IRU
REVHUYDWLRQ ZHOODJH D&H FRPSDUHG DQG VLQFH WKH
REMHFWLYHV DUH PLQLPLJHG WKHWRUHQG PRYHV IURP ULJKW WR WKH
WKLV FDVH OHWdV FRPSDUH VROXWLRQV RI SRLQW & DQG ' DV VKRZQ RQ)LJXUH
'HVSLWH ERWK VROXWLRQV & DQG ' LQ 3DUHWR GRPLQDQFH FRQGLWLRQ DUH
WUXH SRLQW & LV EHWWHU IRU ERWK REMHFWLYHV WKDQ ' EHFDXVH LW UHFRUG
PLQLPXP YDOXH IRU ERWK REMHFWLYHV EHWWHUHQG WEDW
VROXWLRQ & GRPLQDWHV VROXWLRQ ' ,Q RWKHU ZRUGV VROXWLRQ & LV QRW
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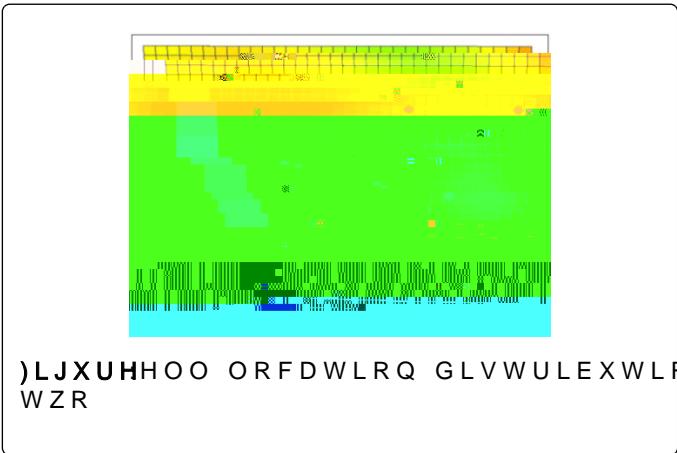
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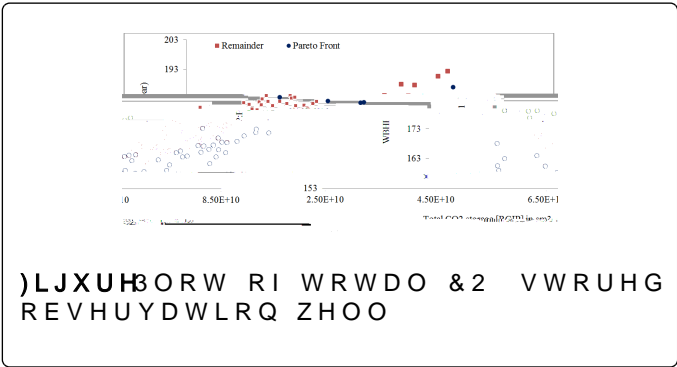
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 TXDOLW\ YDOXH LQ ERWK REMHFWLYHV LV HYLGHQW



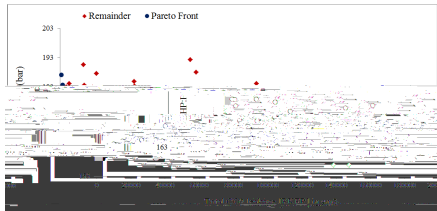
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)LJXUHHO ORFDWLRQ GLVWULEXWLRQV LQ GRPH \$ IRU VROXWLRQ (FDVH
 WZR



)LJXUHBORW RI WRWDO &2 VWRUHG YV ZHOORERWWRPKROH SUHVXUH LQ
 REVHUYDWLRQ ZHOOR



)LJXUH3ORW RDNNDJH YV %RWRPKROH SUHVXUH IRU
 REVHUYDWLRQ ZHOOR

3RLD .HQQHG\ - %ODFNZHOO 7 3DUW%RQWHLZBDRGRSWRLPHV)RWEPQ/LRQ ,QWHUQD
6ZDUP LQWHOO &RQWURO
1JDWF~~R~~XDUHL \$ (O 6KDUNDZL 0\$ 3DUHWR PXOWL REMHFWLYH
RSWLPLVDWLRQ WK ,QWHUQDWLRQDO &RQIHUHQFH RQ ,QWHOOLJHQW 6\ VWHPV
SSOLFQDWLRQ WR 3RZHU 6\ VWHPV \$UOLQJWRQ
:LOOLDPV -'2 -LQ 0 %HQWKDP 0 3LFNXS *(+DQQLV 6' HW DO
ORGHOOLQJ FDUERQ GLR[LGH VWRUDJH ZLWKLQ FORVHG VWUXFWXUHV LQ WKH 8.